Oklahoma Department of Transportation Item 97-11

Identification of Dispersive Soils in Oklahoma by Physiochemical and Clay Mineral Properties

Part I – Final Report Text
Part II – Final Report Database

Final Report submitted by

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May 25, 2000

Technical Report Documentation Page

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE Identification of Dispersive Soils in Oklahoma By Physiochemical and Clay Mineral Properties		5. REPORT DATE April 2000 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Brian J. Carter		8. PERFORMING ORGANIZATION REPORT 10. WORK UNIT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Oklahoma Department of Transportation Research and Development Division 200 N.E. 21st Street, Room 2A2 Oklahoma City, OK 73107		11. CONTRACT OR GRANT NO. Item 2140 13. TYPE OF REPORT AND PERIOD COVERED Final Report January 1997 to April 2000
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Department of Transportation Federal Highway Administration 300 N. Meridian, Room 105S Oklahoma City, OK 73107		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
Done in cooperation with the Okla. DOT, Research and Development Division and the USDA Natural Resources Conservation Service

16. ABSTRACT
Twenty-three soils were sampled across Oklahoma to determine sodic-dispersive characteristics. Twenty-two soils contained sodic properties in some part of their subsoil (within 2 m of the soil surface). Only one of the twenty-two soils was not dispersive as measured by the double hydrometer test. Sodic soils are identified in county soil surveys (NRCS, USDA). County soil surveys can be used to determine areas of sodic soils for many Oklahoma counties. Soil series names used in county soil surveys often did not match or fit soils sampled in this study. Field soil profile descriptions contained only siltans as salient indicators of sodic soils conditions. The presence of siltans failed to predict sodic conditions in the lower subsoil compared to the upper subsoil. Choctaw County contains sodic soils but current soil survey information for this county does not identify soil mapping units that contain sodic soils. Values for soil SAR and EC can be used to predict dispersive soil. The double hydrometer and pinhole tests used together can also predict soil dispersion. The crumb test should not be used as a quick field soil test to predict soil dispersion. Dispersive soils contained a predominance of interstratified illite-smectite clays. The presence of vermiculite and kaolinite in some soils decreased dispersion compared to interstratified illite-smectite. Increased gypsum, bicarbonate, and salt content in soil horizons decreased dispersion compared to soil horizons with low amounts of these materials. Gypsum and leaching with water are proposed amendments for selected sodic soils in Oklahoma.

17. KEYWORDS Sodic soil, sodium adsorption ratio, exchangeable sodium percentage, dispersive soil	18. DISTRIBUTION STATEMENT No restrictions. This publication is available from the Okla. DOT, Research Development Div.		
19. Security CLASSIF. (OF THIS REPORT) Unclassified	20. SECURITY CLASSIF. (OF THIS PAGE) Unclassified	21. NO. OF PAGES	22. PRICE

Project Agreement No. 2140

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SI (METRIC) CONVERSION FACTORS

Approximate Conversions to SI Units					Approximate Conversions to SI Units				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		Length					Length		
in.	inches	24.40	millimeters	mm	mm	millimeters	0.0394	inches	in.
ft	feet	0.3048	meters	m	m	meters	3.281	feet	ft
yd	yards	0.9144	meters	m	m	meters	1.094	yards	yd
mi	miles	1.609	kilometers	km	km	kilometers	0.6214	miles	mi
		Area					Area		
in.^{2}	square inches	645.2	square millimeters	mm^2	mm^2	square millimeters	0.00155	square inches	in.^{2}
ft^2	square feet	0.0929	square meters	m^2	m^2	square meters	10.764	square feet	ft^2
yd^2	square yards	0.8361	square meters	m^2	m^2	square meters	1.196	square yards	yd^2
ac	acres	0.4047	hectares	ha	ha	hectares	2.471	acres	ac
mi^2	square miles	2.590	square kilometers	km^2	km^2	square kilometers	0.3861	square miles	mi^2
		Volume					Volume		
fl oz.	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.0338	fluid ounces	fl oz.
gal	gallons	3.785	liters	L	L	liters	0.2642	gallons	gal
ft^3	cubic feet	0.0283	cubic meters	m^3	m^3	cubic meters	35.315	cubic feet	ft^3
yd^3	cubic yards	0.7645	cubic meters	m^3	m^3	cubic meters	1.308	cubic yards	yd^3
		Mass					Mass		
oz	ounces	28.35	grams	g	g	grams	0.0353	ounces	oz
lb	pounds	0.4536	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000lb)	0.907	megagrams	Mg	Mg	megagrams	1.1023	short tons (2000lb)	T
		Temperature (exact)					Temperature (exact)		
°F	degrees Fahrenheit	(°F-32)/18	degrees Celsius	°C	°C	degrees Celsius	9/5+32	degrees Fahrenheit	°F
		Force and Pressure or Stress					Force and Pressure or Stress		
lbf	poundforce	4.448	newtons	N	N	Newtons	0.2248	poundforce	lbf
lbf/in^2	poundforce per square inch	6.895	kilopascals	kPa	kPa	kilopascals	0.1450	poundforce per square inch	lbf/in^2

Executive Summary

Sodic soils occur in many Oklahoma counties. But additional counties especially in southeastern Oklahoma need field investigation to further identify areas and classify sodic soils. The use of the natric diagnostic subsurface horizon classification (Soil Survey Staff, 1999) to identify sodic soils does not include all sodic-dispersive soils. The natric definition should be expanded to include dispersive soils with sodium adsorption ratio (SAR) values of between 4 to 12 with electrical conductivity (EC) values less than 1 decisiemens per meter and to identify dispersive soil materials in the lower subsoil which are especially important for engineering interpretations. The use of SAR and EC soil values adequately predicted soil dispersion as measured by the double hydrometer method under specific conditions. This relationship was based on a specific data set from Oklahoma soils which 1) were predominantly neutral to slightly alkaline, 2) were moderately clayey (32.0 to 44.2%; mean low and high values for B horizons, respectively), 3) were interstratified illite-smectite clay type, 4) contained calcium as the dominant cation on the soil exchange complex, 5) were dominated by chloride and sulfate anions in the soil-water extract (saturated paste), and 6) contained gypsum in some horizons. SAR and EC could not be used to predict soil dispersion using the relationship developed for the specific data set when, 1) soil pH is acid or strongly alkaline, 2) clay content and type includes vermiculite and kaolinite, 3) magnesium and not calcium dominated the soil exchange complex, 4) bicarbonate compared to sulfate and chloride dominated the soil water extract and 5) gypsum is present in the soil. The pinhole test is recommended for the prediction of dispersion. Pinhole test value of slightly dispersive (ND3) and greater should be used to indicate dispersion. The pinhole test should be used in conjunction with the double hydrometer test and soil SAR and EC values to predict dispersive soils. The crumb test should not be used as a quick field test for identifying dispersive soils. Laboratory results indicate successful remediation of sodic soils using several amending material (especially gypsum and calcium chloride) and that remediation becomes more difficult as the amount of salts and sodium increase in the soil solution. Leaching (successive additions and removal of water) in conjuction with addition of amending materials (especially gypsum) resulted in improved remediation. Laboratory results need validation by field studies before being implemented.

Table of Contents

Part I

Part II – Database to Final Report is bound separately and includes the following Table of Contents:

Part II

page

List of Tables

List of Figures

page

INTRODUCTION

Overview

Sodic soils occur in Oklahoma and adversely affect roadway construction, maintenance, and plant growth. Sodic soils are also called dispersive soils indicating the dispersion of small soil particles (especially clays) within soil horizons. Sodic soils are unique because they contain significant amounts of sodium (Na^{+}) compared to calcium (Ca^{+2}) and magnesium (Mg^{+2}) on cation exchange sites of soils and in pore water. This greater Na^{+} content in sodic compared to normal (non-sodic) soils produces distinct physiochemical soil characteristics. Distinct physiochemical soil characteristics produced by sodic soils include increased in-situ bulk densities, adjunct saline conditions, decreased soil saturated hydraulic conductivity, and increased soil dispersion compared to non-sodic soils. Extremely poor plant growth conditions occur when sodic soils are disturbed by tillage operations. Extremely poor roadway construction materials are produced when sodic soils are used as roadway subgrade or fill. Sodic soils, whenever possible, should not be disturbed unless intensive remediation is given to correct their unique physiochemical soil characteristics.

Sodic soils present problems for crop production, range management, horticulture, and engineering purposes (such as road and bridge construction). The causes of saline and sodic soils in Oklahoma are poor drainage, salty irrigation water, oil field waste, and the saline-sodic soil parent material (Stiegler, 1986 and Johnson, 1990). When sodic soil is used as a fill or borrow material, pipes and tunnels form in roadways and structures leading to collapse of roads and bridges (Knodel, 1991). Sodic soils in Oklahoma occur in spots of irregular size and shape at various topographic locations (Reid et al., 1993). Sodic soils that occur in Oklahoma form in alluvium and residuum derived from shales of the Permian and Pennsylvanian periods (Ryker, 1977).

Reclamation of sodic soils is achieved by applying chemical amendments to lower the exchangeable sodium percentage (ESP) of the soils to below 15. Chemical amendments are materials that supply a divalent cation such as Ca^{2+} to replace Na^{+} on the exchange sites of the soil. The Ca^{2+} can originate from the dissolution of calcium containing amendments or irrigation water. The rate at which sodic soils can be reclaimed depends upon many factors including the rate of water flow through the soil profile, the concentration of Ca^{2+}, texture of the soil, ESP and the depth and thickness of the sodic horizon (Quirk and Schofield, 1955).

Scope and Purpose of Work

Soils that disperse will 1) erode easily and form pipes and tunnels in embankments, in cut slopes or behind bridge backwalls 2) cause continuous erosion and sediment problems to roadway structures, and 3) sometimes develop hazardous roadway conditions. The use of dispersive soils as fill during bridge and roadway construction creates costly maintenance because of settling of approach slabs and roadway subsidence. The lack of soil characterization data limits dispersive soil identification and remediation.

This report contains a problem prevention and remediation component. Future use of dispersive soils in roadway construction can be eliminated or greatly reduced. Preventing use of dispersive soils during roadway construction will save money and time, increase roadway safety, improve plant growth, and reduce soil erosion and pollution. A large part of this report concerns preventing roadway problems by identifying, characterizing, and determining spatial distribution of dispersive soils. A smaller but important report consideration is the remediation of dispersive soils currently causing roadway problems. The report contains recommendations on the physical and chemical treatments needed to remediate dispersive soils. Future engineering techniques will include these treatments and obtain benefits by improving plant growth, reducing soil erosion, and limiting roadway failure caused by dispersive soil materials.

Results can be applied immediately to proposed roadway construction and to current problem areas. Potential problem soils can be identified through computer generated maps and supporting soils database. Dispersive soil areas can be avoided as unsuitable construction materials or treated to correct poor soil conditions. Proposed remediation methods and materials produced from this project can be tested in current problem areas. Research findings and proposed remediation will need further field testing and engineering design before application.

Objectives of the study include 1) identify and characterize soil series that have natric (sodic-dispersive) horizons in Oklahoma, 2) develop county soil maps showing locations of dispersive soils, 3) develop soils database to support map units containing dispersive soils, and 4) determine treatments for remediation of dispersive soils.

LITERATURE REVIEW

Genesis of Sodic Soils

Sodic soils include Natric Great groups of Mollisols, Alfisols and Aridisols. Previously sodic soils were classified as solonchaks, solonetzes, or solods. Sodic soils have soluble salts in the lower depths in the soil profile. Sodic soils are characterized by the development of relatively impervious, strong columnar B horizon structure (McGregor and Wyatt, 1945) which is characterized by high exchangeable sodium (15% and more) on the soil colloidal complex and high sodium adsorption ratio (SAR more than 13) in the soil water extract (McBride, 1994).

The initial theory of the development of sodium affected soils was proposed by the Russian scientist K.K. Gedroitz (1927). Gedroitz's theory requires the presence of a water table, either permanent or ephemeral, close enough to the soil surface to be affected by evapotranspiration, with a consequent upward convective movement of sodium (Gedroitz, 1927; Kellog, 1934; Kelley, 1934; MacGregor and Wyatt, 1945; Bentley and Rost, 1947; Westin, 1953; Whittig and Janitzky, 1967; Arshad and Pawluk, 1966; Rassmussen et al., 1972; Lewis and Drew, 1973; Fullerton and Pawluk, 1987; Miller and Pawluk, 1994). Other conditions necessary for the development of soils with natric horizons are arid or semiarid climates and periods of temporary excessive moisture interspersed with dry periods, impeded drainage, low slope gradients, and textural discontinuities created during deposition of sediments such as eolian, glacial or alluvial materials (Levy, 2000). Dispersive soils develop on sodic-saline parent material.

The classic theory views solonetz soils (natric soils) as one stage in the evolution of the sodic soils (solonchak, solonetz, solod) that is summarized as follows (Gedroitz, 1927):

1. Normal soils. In these soils the base exchange is saturated with the divalent cations (mainly Ca^{2+}), the colloids are flocculated.
2. Saline soil (solonchak). Salt accumulates in the soil and on the surface (given a shallow water table). The process is called salinization. Usually a portion of divalent cations on the exchange is replaced by monovalent cations, especially sodium. The presence of excess salts (Cl^-, $SO_4^{=}$) prevents the hydrolysis of the sodium from the exchange and this keeps the colloids flocculated.
3. Sodic soil (solonetz). These soils have a relatively high amount of exchangeable sodium and a low amount of soluble salts. Sodium displaces only a part of the exchangeable calcium and magnesium. This happens only in the case of a high concentration of sodium in soil solution as compared with calcium and magnesium together. However, if there is a slow rate of lowering of the water table, the ground water will add more sodium salts – by capillary rise through the soil stratum, followed by evaporation, during the hot season. During the rainy season, soluble salts are leached. The amount of exchangeable sodium gradually increases. Given a high content of sodium on the exchange, removal of salts causes increased mobility of colloids and the soil becomes highly alkaline as a result of the hydrolysis of the sodium.
4. Sodic soil (solod or sometimes soloth). Upon further leaching of salts, dispersed colloids move downward, accumulate in the subsoil, and form a compact clay-rich subsoil (natric horizon) that is slowly permeable to water. Exchangeable hydrogen increases and soil pH decreases. The process is called solodization. Presence of $CaCO_3$ prevents solodization. In this case, during leaching, calcium displaces the absorbed sodium on the soil exchange complex, preventing the soil from degrading (containing a compact clay-

rich subsoil). Rode (1955) suggests that vegetation contributes to the shifting (biocycling) of calcium from the lower parts of the profile into upper horizons.

Later studies support and evolved the classical theory (Kellog, 1934; Kelley, 1934; MacGregor and Wyatt,1945; Bentley and Rost,1947; Westin, 1953; Whittig and Janitzky,1967; Arshad and Pawluk,1966; Rassmussen et al., 1972; Lewis and Drew,1973; Fullerton and Pawluk, 1987; Miller and Pawluk, 1994). Kellog (1934) found that normal soil, solonchak, solonetz, and solod occur in complexes. He also described two types of solonetz depending on source of salts: uniform and complex. Uniform solonetz develop in old ponded areas usually from parent materials of heavy clay, either of lacustrine or alluvial origin. Complex solonetz, the most common, develop because of capillary rise of salts from the water table and occur as "solonetz-complex".

Kelley (1934) emphasized the role of soluble salt composition in the process of solonization. The presence of soluble calcium salts tends to prevent the saturation of the soil exchange complex with sodium. As was shown by Russian investigators, solonetz forms from solonchak only if the Na^{+}/ (Ca^{2+}+Mg^{2+}) is greater than 4 or if calcium salt content is less than 20% (Kaurichev et al., 1989). Sources of sodium salts vary depending on local conditions. Neutral sodium salts (chlorides and sulfates) are derived from sedimentary parent rock, carried into the soil by atmospheric dust, precipitation, or by saline ground water (Rode, 1955). A principal way in which alkaline sodium salts (soda) form in soils is a reaction between soluble sodium salts and calcium carbonates ($CaCO_3$) (Kelley, 1951). Later studies proposed the importance of biological formation of soda (Whittig and Janitzky, 1967) in water-logged soils with high water tables and high organic matter. Rode (1955) reported positive relationships between sulfate-bearing waters and strongly alkaline, sodium-saturated soils, having substantial soda accumulations. Soil microorganisms reduce sulfate to sulfide. Sulfides of calcium, magnesium and sodium upon hydrolysis give corresponding hydroxides, which upon reacting with H_2CO_3 give calcium, magnesium and sodium bicarbonates. Sodium bicarbonate remains soluble and moves with capillary water and accumulates as water evaporates from the soil surface. Loss of carbon dioxide (CO_2) results in formation of soda.

Other research suggests that several processes influence the formation of natric (sodic) horizons in soils (Lewis et al., 1959; Wilding, 1963; Munn and Boehm, 1983; Johnson et al.; 1985; Reid et al., 1993). Lewis et al., (1959), Munn and Boehm (1983), and Johnson et al., (1985) studied systems in which water tables did not play a role in solonetz soil formation. Munn and Boehm (1983) showed that in the Northern Great Plains (Montana), solonization is driven by reduced infiltration and subsurface salty water movement in response to matric and osmotic potential gradients. The process happens at an elevated point in the till-shale boundary where the annual wetting front reached into the salty calcareous shale. Wilding (1963), in studying solonetzic soils in Illinois, found that differential redistribution of soluble sodium from weathering of sodium-rich feldspars in non-saline loess is responsible for sodium accumulation in the soils. Local distribution of solonetz soils was correlated with more permeable till zones within the relatively impervious underlying Illinoian till paleosol. Other studies concluded that natric horizons form through deposition of salt dust from nearby playas (Ballantyne, 1978; Peterson, 1980; Reid at al., 1993). After deposition the salts and the clay from the dust are moved downward and accumulate in the subsoil to form a natric horizon.

These theories have one thing in common: to evolve the unique structure and properties of sodic soils, a large proportion of sodium is needed on the exchange complex. Cation exchange reactions lead to sodium eventually occupying a significant part of the exchange complex (15% and more). The sources of sodium and processes that result in accumulation of sodium in upper soil horizons are different for various locations. (Theories of genesis for sodic soil must reflect local climate, landform, and material in which the soil formed.) For most sodic soils, sodicity is a natural phenomenon related to the nature of the parent material and subsequent pedogenic processes affected by the interplay of moisture and temperature. These processes are responsible for differentiating the soil profile into layers (horizons). There are also sodic soils where sodicity arises from anthropogenic processes and is called secondary solonization or salinization. Irrigation without proper drainage, forest clearing, and other land management practices that can lead to waterlogging yield rapid and secondary solonization or salinization (Levy, 2000).

Murphy and Daniel (1935) proposed a model for the genesis of sodic soils in central Oklahoma. The presence of alkali spots is believed to be due to accumulation of sodium salts in the sediments laid down by receding sea, as the waters in the deeper surface reservoirs evaporated as a result of arid conditions (Murphy and Daniel, 1935). Later work at Oklahoma State University on sodic soils of north central Oklahoma suggested the following sources of sodium: 1) outcropping ground water which is high in soluble salts from localized evaporates (Stewart, 1969), and 2) in situ weathering of sodium-rich feldspars (Bakhtar, 1973). Reed (1962) and Chotivanich (1972) reported that the saline –alkali soils of Oklahoma usually occurred in response to one or more of the following processes: (1) detrital salts in soils formed from alluvium or the deposits of salts on the flood plains of the Arkansas River; (2) by evaporation of saline water from a perched water table above an impervious subsoil; (3) sodic spots that occur in local areas of soil parent material of saline-alkali Permian and Pennsylvanian shales, (4) by contamination of salt water separated from a mixture of oil and salt water; and (5) by use of saline irrigation water. According to Reed (1962), the Salt Fork of the Arkansas River, the Cimarron River east of Enid, and the Elm Fork of the Red River are salty and the salt is derived from rocks in the drainage basins of these rivers.

Mechanism for Clay Dispersion

Hydrated monovalent cations such as sodium, that are not tightly held by the clay enhance clay dispersion (Knodel, 1991). Dispersion is the repulsion of negatively charged soil particles. Dispersed soils erode quickly because individual clay particles are easily transported by wind and water. The classic approach presents clay dispersion as a combination of sodicity (relative amount of sodium ions versus calcium and magnesium ions (sodium adsorption ratio)) and electrolyte concentration (amount of soluble salts in soil) in soil-pore water. Soil sodicity is expressed as the sodium adsorption ratio (SAR):

$$\mathrm{SAR} = \frac{(Na^{+})}{\sqrt{(\mathrm{Ca}^{2+}) + (\mathrm{Mg}^{2+})/2}}$$ where Na^{+}, Ca^{2+} and Mg^{2+} are concentrations of respective ions in milliequivalents/liter (meq./l) for a soil-water extract. The electrolyte concentration is a measure of soil salinity from a soil-water extract and expressed as electrical conductivity (EC; decisiemens per meter (ds/m)) (Richards, 1954). Salt prevents soil particles from dispersing. Another measure of dispersibility of soils is exchangeable sodium percentage (ESP), a function of relative concentration of sodium on the soil exchange complex compared to the total amount of charge on the exchange complex (McBride, 1994). If greater than 6% of the exchange complex is occupied by sodium ions clay particles start to disperse. If ESP is greater than 15%, almost all clay particles disperse. Obtaining reliable exchangeable ion data is difficult, and SAR of soil solution becomes the principle parameter for diagnosing sodic hazard in soils. The relationship between SAR and ESP is linear (Richards, 1954).

SAR and EC values for soils provide a basis for evaluation of the structural stability of sodium affected soils: a threshold concentration curve partitions chemical conditions that destabilize soil structure from those under which structure is stable (Curtin et al, 1995). Each soil has a unique relationship producing values of sensitivity to sodicity. In the US, soils with SAR values of more than 13 and EC less than 4 decisiemens/meter (ds/m) are considered dispersive. In Australia, much lower values for SAR compared to the US were adopted (Naidu et al., 1993). Factors that might account for different sensitivities are soil texture, bulk density, mineralogy, iron oxides, organic matter content, and types and amounts of exchangeable cations or carbonates. Sensitivity of soils to large amounts of sodium and low electrolyte concentrations increased with increasing bulk density and clay content (Frenkel et al., 1978). Clay minerals found commonly associated with dispersive soils are smectite and illite (Frenkel and Meiri, 1985). The type of clay mineral also influences the response of soils to sodic conditions. Soils with large amounts of expanding 2:1 layer silicates are the most unstable (dispersive) while soil high in kaolinite and sesquioxides are stable (non-dispersive) (McNeal and Coleman, 1966; Yaron and Tomas, 1968). Acidic kaolinitic are insensitive to changes in soil sodicity. However, with addition of smectitic impurities to these soils, susceptibility to sodic conditions increased markedly (Frenkel, et al., 1978). Among the 2:1 layer silicates, smectitic soils have greater sensitivity to sodicity than vermiculitic counterparts (Rhoades and Ingvason, 1969).

Sodic soils containing minerals that readily release soluble electrolytes like gypsum ($CaSO_4^{2}$ H_2O) for example, are less dispersible when leached because they will maintain relatively high salt concentrations in soil solutions (Alperovich et al., 1981). Dispersion is limited in calcium sulfate saturated soils because sulfate maintains a high electrolyte concentration (Frenkel and Meiri, 1985). Iron oxides have a cementing effect in the soil (Frenkel et al., 1978) which prevents dispersion in some sodic soils. High-charge cations such as aluminum also promote flocculation (McBride, 1994). The presence of Mg^{2+}, compared to Ca^{2+}, enhances clay dispersion in soils with mixed (Ali et al., 1987, Yousaf et al., 1987), kaolinitic (Emerson and Smith, 1970) and illitic mineralogy (Rengasamy et al., 1986). In some kaolinitic soils, the adverse effect of Mg^{2+} has not been noted (Levy et al., 1989). Elevated exchangeable Mg^{2+} levels can cause deterioration of soil structure resulting in development of magnesium-solonetz (Ellis and Caldwell, 1935). Furthermore, aggregates saturated with Na^{+} and Mg^{2+} disperse at lower ESP than those saturated with Na^{+} and Ca^{2+} (Emerson and Bakker, 1973; Ali et al., 1987). In calcareous soils, the presence of Mg^{2+} enhances the dissolution of calcium carbonate, thereby producing electrolytes that prevent clay dispersion. Soil organic matter (SOM) acts as a bonding agent in soils. SOM inhibits soil aggregate breakdown. Increased amounts of SOM seem to promote resistance to sodic-dispersive conditions.

Arora and Coleman (1979) observed that increasing pH resulted in increasing dispersion in soils and Suarez et al. (1984) suggested that soils with large amounts of variable charge (variable charge minerals, organic matter) are most susceptible to dispersion caused by pH effects.

The susceptibility of sodic soils to dispersion depends on soil texture. Soils with 10 to 30% clay are the most susceptible to dispersion. With increasing clay content, soil structure is more stable and in soils with less than 10% clay, the amount of clay available to disperse and clog soil pores was limited.

Agronomic Properties of Sodic Soils

Under intensive cultivation, soils lose a large proportion of organic matter content responsible for water-stable aggregation. With progressively increasing time under cultivation, many soils have been shown to become more sensitive to the adverse effect of sodium whether introduced in irrigation water or originally present in the soil. This increased sodium sensitivity results in soils with poor physical conditions which are prone to seal formation and erosion (Sumner, 1998). Deep fertile soils are transformed into eroded and less productive soils. Sodic soils usually have poor physical and chemical properties, particularly when the electrolyte or dissolved salt concentration of the soil solution is inadequate to compensate for the effects of exchangeable sodium on the swelling and dispersion of clay (Oster et al., 1995).

A commonly encountered physical problem associated with sodicity on croplands is slow water infiltration, which results in poor soil water storage and the need to irrigate more frequently (McKenzie et al., 1993). When sodic soils are wet, problems of slow water entry into the soil and slow internal drainage, poor aeration, trafficability and compaction commonly occur because of low soil hydraulic conductivity (Ford et al., 1993). Soils high in sodium are difficult to till and germination of seedlings are restricted (Tisdall and Adem, 1988). Excess sodium on the exchange complex imparts structural instability to the soil giving poor physical properties. The infiltration rate and permeability of soils affected by sodium is reduced. For this reason the surface layers remain nearly saturated for prolonged periods following irrigation or rain resulting in temporary anaerobic conditions.

Increased amounts of sodium in soil causes deficiencies of calcium in plants (Sumner, 2000). Sodic soil conditions affect plant growth and crop yield by decreasing solubility and availability of nutrients such as zinc, phosphorus, and iron due to high pH, calcium carbonate, and soluble biocarbonate (HCO_3^-), and carbonate (CO_3^{2-}) (Chhabra, 1996). Sodic soils are generally deficient in available nitrogen (Rao and Batra, 1983). Plant population decreases because of a high rate of mortality during early stages of growth in sodic soils. For successful crop production, exchangeable sodium percentage (ESP) of the soil, must be below 15 often requiring application of amendments (Sumner, 2000).

Most amendments are those materials that directly supply soluble calcium for the replacement of exchangeable sodium. Sodic soils are reclaimed by chemical amendments, drainage, cropping, and tillage operations. Chemical amendments such as gypsum, calcium chloride, hydrated lime have been used for many years for the treatment of croplands effected by sodium (Abrol, et al., 1988).

Presence of sodium carbonate in sodic soils results in the formation of soluble sodium phosphates and correlates with electrical conductivity (EC) and soluble phosphorus status (Chhabra and Abrol, 1981). If a soil contains significant amounts of sodium carbonate (and also soluble phosphorus), most of the soil calcium is in the calcium carbonate form and not available to the plants resulting in crop failures. Application of an amendment like gypsum to improve sodic soils, results in converstion of the soluble sodium phosphates to less soluble calcium phosphates. Chhabra and Abrol (1981) observed that crops grown in recently reclaimed sodic soils did not respond to applied phosphorus fertilizers for 4-5 years because of the increased availability of phosphorus.

Proper choice of crops during reclamation of sodic soils is important. Crops tolerant to excess exchangeable sodium are available. The effects of varying levels of exchangeable sodium influences the performance of crops and much variation visits in the tolerance of crops to sodic conditions (Abrol, et al., 1988; Chhabra et al., 1979). Rice and dhaincha (sesbania aculeata), appear to be tolerant. Wheat, barley, oats, cotton, sugarcane and bajra (pennisetum typhoideum), are moderately tolerant and legume crops like mash (phaseolus mungo), lentil (lens esculentum), cowpeas, groundnut, maize, and peas are relatively sensitive to excess exchangeable sodium

(Kumar and Abrol, 1986;). Grasses are in general more tolerant of sodic conditions than most field crops. Grasses that are reported to be tolerant to sodicity are Karnal grass (Diplachne fusca), Rhodes grass (Chloris gayana), and Bermuda (Cynodon dactylon) (Kumar and Abrol, 1986). Karnal grass is successfully grown in soils of very high ESP (80-90). Cultivation of grasses causes a continuous decrease in sodicity with time and an improvement in soil physical properties because of the biological action of grass roots.

Unfavorable soil conditions (high pH and high levels of ESP) in subsoil layers in sodic or partially reclaimed sodic soils restrict root penetration of crops to lower soil layers. Roots only penetrate the upper few centimeters depending upon the degree of soil improvement. The amount of soil available for moisture extraction following irrigation decreases because of confinement of crop roots to surface layers of the soil.

The available water storage capacity of sodic soils is decreased because of lower soil moisture retention at low suction values and higher retention at higher suction values (Abrol et al., 1988 and Sumner, 2000). The effective capacity of soils to supply water is further reduced because of the poor soil hydraulic conductivity of sodic soils which seriously limits water movement from lower soil layers to meet evapotranspiration. As a result, the supply of available water for plants diminishes rapidly and requires replenishment at shorter intervals. Sodic soils with limited root penetration, lowered capacity to store water in an available form, and poor transmission characteristics need more frequent irrigation than normal soils.

Engineering Properties of Sodic Soils

Dispersive soils are subject to surface sealing and crusting (Shainberg 1984). Increased runoff from sodium rich soil results in severe rill and tunnel erosion on slopes and slumping of embankments, and undermining and clogging of roadside drains causing floods in low-lying areas. Sodic soils with low wet bearing strength deform easily under pressure when wet, making site access difficult and such soils unsuitable for foundations. Soil strength, settlement, and swelling are properties that affect roads and streets because they influence ease of excavation, grading, and traffic supporting capacity (Sherard et al., 1977).

The colloidal dispersibility of soil can be directly measured by the pinhole test in which distilled water flows through the soil under a specific head (Sherard, 1976). Pinhole tests simulate a leak in a clay dam, imitate soil behavior in the field, and provide reliable and reproducible results (Statton and Mitchell, 1991). However, prior to testing, samples should be maintained at their natural moisture content because air-drying can cause some normally non-dispersive clays to disperse during the pinhole test (Shafer, 1978). Nickel (1977) indicated that only the Emerson crumb test and the pinhole test directly model the condition for clay dispersion where shear stress applied by hydraulic flow must exceed the shear strength of the zone of expansion.

One of the simplest tests is the crumb test (Emerson 1967), which can be used in the field. This test depends on the pH value of the pore water and may be influenced by the clay minerals present. Although the crumb test gives a good indication of the potential erodibility of soils, a dispersive soil sometimes may give a non-dispersive reaction (Bell and Maud,1994). Craft & Acciardi (1984) found that the crumb test and the pinhole test at times yield conflicting results for the same soil. Subsequently, Gerber & Harmse (1987) showed that the crumb test, the double hydrometer test, and the pinhole test were unable to identify dispersive soils when free salts were present in the soil-water solution, which is frequently the case with sodium saturated soils. Craft & Acciardi (1984) concluded that pore water cation data (SAR, alone) does not provide adequate identification of dispersive and non-dispersive soil. Similarly, activity (plasticity index/clay content) does not necessarily provide a parameter for distinguishing between dispersive and non-dispersive soils. There is no direct correlation between dispersivity as measured by the crumb test and the liquid limit, plasticity index, or amount of clay in the soil. Richie (1963) and Knodel (1991) set an arbitrary limit equivalent to 30% dispersion (double hydrometer tent) of particles smaller 0.005 mm, above which the soil would be considered to be susceptible to tunneling failure. According to Crouch et al. (1991), subsequent experience with several soils confirmed 30% dispersion by the double hydrometer method to be a useable limit.

Bill and Maud (1994) noted that dispersive soils can present problems in road construction on both the fill and cut slopes. Use of dispersive soils in embankments is possible if dispersive material is covered with better class material. Proper placement and compaction of fill layers should be done with care to prevent shrinking and cracks that create paths for erosion of dispersive soils. In areas where seepage and springs are located along the alignment of a road embankment, that has to be constructed of dispersive material, adequate subsoil drainage is necessary; otherwise the embankment could be jeopardized by the development of piping, tunnel and gully erosion in the dispersive soils that could lead to the collapse of roads. Sherard et al. (1977) and Bell and Maud (1994) noted that failure of dams with dispersive soils can be prevented if an earth dam is built with careful construction control and incorporates filters. Tandanier & Ingles (1985) proposed that soils used in earth dams should have less than 6% air voids and clay content should exceed 20% and the linear shrinkage should be less than 7%.

Hydrated lime, gypsum and aluminum sulfate have been used to treat dispersive clays used in earth dams. McDaniel and Decker (1979) found that the addition of 4 % by mass of hydrated lime converted dispersive soil to non-dispersive soil. However, lack of homogenous mixing of lime with the soil may create brittleness and cracks on the dam. According to Melvill and Mackellar (1980) the use of hydrated lime for soil stabilization in dam construction have been avoided in South Africa (Cape Province) Elandsjagt dam. Gypsum because of its relatively low cost and reasonable solubility in water in a powder form has been used as another stabilizing material (Grant et al. 1977).

SODIC SOIL CLASSIFICATION

Introduction

Twenty-three soil profiles (2m depth) were sampled as representative of the key sodic soils of Oklahoma as identified by NRCS-USDA county soil maps (Table 1 and Figure 1). Resource Soil Scientists NRCS-USDA (R. Clay Wilson, Dwaine Gelnar, John Haberer, and Rick McCright) assisted in selection and sampling of these sodic soils.

In currently published county soil surveys (USDA-NRCS) sixteen soil series are identified as natric (sodic) (containing dispersive subsoils when exposed at the ground surface). These soils occur naturally in 40 of the 77 Oklahoma counties. Soil materials that are also identified as dispersive include "slickspots". Initially the following natric (sodic) soils were identified in the study as occurring in Oklahoma:

Soil Series	Taxonomic Class
Bonn	Fine-silty, mixed, thermic Glossic Natraqualf
Carytown	Fine, mixed, thermic Albic Natraqualf
Doolin	Fine, smectitic, thermic Typic Natrustoll
Drummond	Clayey/loamy, mixed, thermic Mollic Natrustalf
Dwight	Fine, smectitic, mesic Typic Natrustoll
Foard	Fine, smectitic, thermic Vertic Natrustoll
Healdton	Fine, mixed, thermic Vertic Natraqualf
Hinkle	Fine, smectitic, thermic Mollic Natrustalf
Huska	Fine, mixed, thermic Mollic Natrustalf
Lafe	Fine-silty, mixed, thermic Glossic Natrudalf
Oscar	Fine-silty, mixed, thermic Typic Natrustalf
Pawhuska	Fine, mixed, thermic Mollic Natrustalf
Seminole	Fine, mixed, thermic Typic Natrustoll
Wakita	Fine-silty, mixed, thermic Leptic Natrustoll
Wing	Fine, mixed, thermic Aquic Natrustalf
Wister	Fine, mixed, thermic Vertic Natrudalf.

Table 1. Site descriptions of soils sampled for ODOT Item #2140-dispersive soils.

Site No.	Soil mapping unit	Unit symbol	County	Legal description	Soil Survey Sheet #	Adjacent soil mapping unit.	Unit Symbol
1	Bosville sandy loam, 4-8% slopes	9	Choctaw	SE1/4 NW1/4 Sec.20 T6SR15E	34	Muskogee silt loam, 1-3% slopes	36
2	Parsons-Dwight complex, 1-3% slopes, eroded	PdB2	Pittsburg	NW1/4 SE1/4 Sec.22 T8NR14E	15	Parsons silt loam, 0-1% slopes	PaA
3	Wing silt loam, 0-2% slopes	82	Le Flore	SW1/4 SW1/4 Sec.16 T9N R24E	10	Wister silt loam, 1-3% slopes	84
4	Wister silt loam, 0-1% slopes	83	Le Flore	SW1/4 NE1/4 Sec.34 T8NR26E	27	Wing silt loam, 0-2% slopes	82
5	Bethany-Pawhuska complex, 0-3% slope	5	McClain	NE1/4 SE1/4 Sec.1 T7NR3W	14	Bethany silt loam, 0-1% slopes	3
6	Lafe soils	La	Sequoyah	NE1/4 NE1/4 Sec.1 T11NR24E	44	Stigler silt loam, 1-3% slopes	SrB
7	Parsons-Carytown silt loam, 0-1% slopes	55	Muskogee	SW1/4 NW1/4 Sec.4 T13NR18E	38	Taloka silt loam, 0-1% slopes	70
8	Dwight-Parsons silt loams, 0-1% slope	DwA	Okmulgee	SW1/4 NW1/4 Sec.20 T12NR12E	51	Okemah silt loam, 0-1% slopes	OkB
9	Doolin-Pawhuska complex	51	Cleveland	NE1/4 NE1/4 Sec.33 T10NR3W	10	Doolin silt loam, 0-1% slopes	50
10	Brewer-Drummond complex	Bu	Canadian	NW1/4 SW1/4 Sec.19 T14NR9W	10	Dale silt loam	Da
11	Apperson-Dwight complex, 0-3% slopes	2	Osage	NW1/4 NW1/4 Sec.28 T29NR7E	8	Foraker-Shidler complex, 12-25% slopes	23
12	McClain-Drummond silt loams, rarely flooded	35	Grant	NE1/4 NW1/4 Sec.18 T26NR4W	50	McClain silt loam	34

Table 1. Site descriptions of soils sampled for ODOT Item #2140-dispersive soils (con't.).

Site No.	Soil mapping unit	Unit symbol	County	Legal description	Soil Survey Sheet #	Adjacent soil mapping unit.	Unit Symbol
13	Zaneis-Huska complex, 1-5% slopes	81	Payne	NE1/4 NW1/4 Sec.10 T19NR2E	14	Renfrow-Urban land complex, 1-5% slopes	80
14	Doolin silt loam	96	Payne	N1/2 NE1/4 Sec.2 T19NR4E	17	Zaneis-Huska complex, 1-5% slopes	72
15	Okemah-Parsons-Carytown complex, 0-1% slopes	44	Tulsa	E1/2 SE1/4 Sec.3 T19NR14E	25	Dennis silt loam, 3-5% slopes	13
16	Seminole loam, 0-2% slopes	78	Payne	S1/2 SE1/4 Sec.4 T17NR6E	54	Chickasha-Seminole complex, 2-5% slopes	77
17	Healdton silt loam	15	Carter	NE1/4 SW1/4 Sec.35 T3SR2E	31	Watonga silty clay	43
18	Zaneis-Wing complex, 0-3% slopes	ZwB	Jefferson	NW1/4 SW1/4 Sec.8 T4SR6W	12	Zanies-Lucien-Vernon association, rolling	ZvD
19	Port-Oscar complex	Po	Jefferson	SE1/4 SW1/4 Sec.26 T4SR7W	19	Zanies-Wing complex, 0-3% slopes	ZwB
20	Foard silt loam, 0-1% slopes	FaA	Comanche	NE1/4 SE1/4 Sec.22 T1NR12W	78	Foard and Tillman soils, 1-3% slopes	FtB
21	Asa-Oscar complex	Ax	Tillman	SW1/4 SW1/4 Sec.3 T1SR15W	18	Indiahoma silty clay loam, 3-5% slopes	InC
22	St-Paul-Hinkle complex, 0-1% slopes	SbA	Kiowa	NE1/4 SE1/4 Sec.23 T2NR17W	19	Carey-Hinkle complex, 1-5% slopes	CbD
23	Renfrow-Hinkle complex, 1-3% slopes	47	Grady	NE1/4 NW1/4 Sec.19 T8NR7W	28	Renfrow silt loam, 1-3% slopes	44

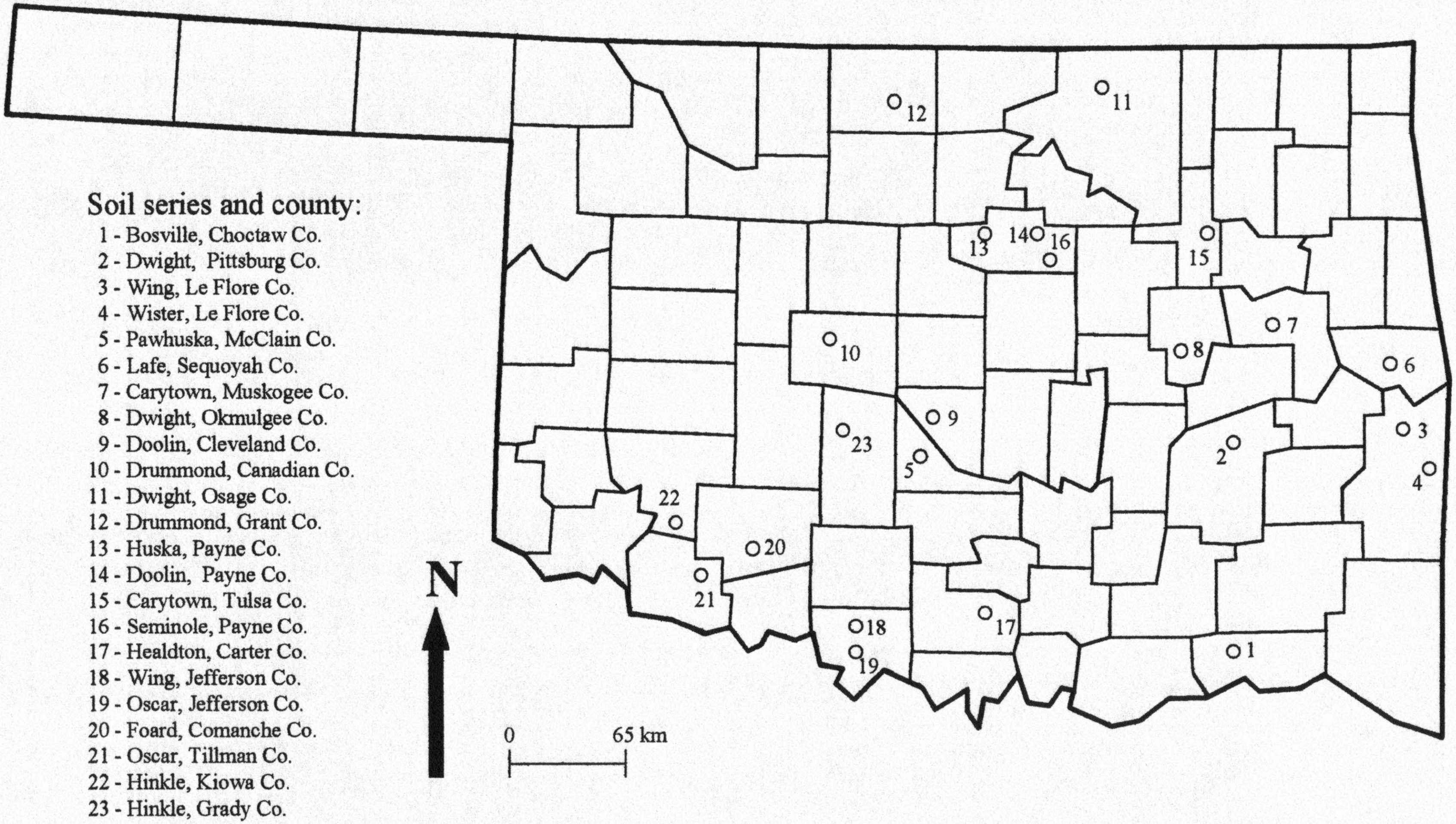


Figure 1. Sampling locations for sodic-dispersive (natric) soils in Oklahoma.

The counties contain a range in aerial extent of sodic soils from 0.1 to 36% (Table 2 and Figure 2). The counties containing dispersive soils are divided into the southeast: Pottawatomie, Pontotoc, Seminole, Coal, Hughes, Pittsburg, McIntosh, Latimer, Haskell, Sequoyah, LeFlore; northeast: Payne, Osage, Washington, Tulsa, Rogers, Craig, Wagoner, Okmulgee, Muskogee; northwest: Kay, Noble, Grant, Alfalfa, Garfield, Blaine, Kingfisher, Canadian, Oklahoma; southwest: Kiowa, Caddo, Grady, McClain, Cleveland, Comanche, Tillman, Cotton, Jefferson, Carter, Love. The dispersive soils are found in several different landscape positions and form in several different parent materials (sediments) (Table 3). Subsoil (B horizons) soil textures are usually clayey (11 of 15) or silty (4 of 15). Surface soil textures are typically a silt loam (13 of 15) with two soils containing a loam soil surface texture. Most soils contain 4 distinct layers (horizons). Sodic soils are usually deep and contain a water table within the soil (Table 4). Six of the fifteen dispersive soils are only found in one quadrant in Oklahoma. The Bonn Series is found in Wagoner County only (northeast), the Wakita series is found in Grant County only (northwest), the Lafe and Wing series in the southeast, and the Foard and Healdton Series in the southwest.

Soil Taxonomy of Sampled Soils

The classification of sampled soils was determined based on data from the study using the most current Soil Taxonomy (Soil Survey Staff, 1999). Out of 23 soils sampled, 5 were not placed in a natric (sodic) Great Group category (Table 5). Four of these soils are from eastern Oklahoma: Bosville (Choctaw Co.), Dwight (Pittsburgh Co.), Dwight (Okmulgee Co.), Carytown (Muskogee Co.). These soils had SAR greater than or equal to 13 but were below the specified taxonomic depth, or had SAR less than 13 through the required thickness (criteria for classifying horizon as natric).

Table 2. Soil mapping units containing sodic soils in Oklahoma Counties.[1]

SERIES	COUNTY	MAP UNIT NAME & CODE	ACRES	%[1]
Bonn	Wagoner	Bonn silt loam, clayey subsoil variant (Bv)	561	0.2
Carytown	Coal	Carytown silt loam, thin surface (Ca)	5105	1.5
Carytown	Coal	Lightening - Carytown cmpx (Lg)	4125	1.2
Carytown	Craig	Carytown silt loam, thin surface (Ca)	904	0.2
Carytown	Craig	Lightening - Carytown cmpx (Lg)	5915	1.2
Carytown	Muskogee	Parsons - Carytown silt loam, 0-1% slopes (55)	1960	0.4
Carytown	McIntosh	Carytown silt loam, 0-1% slopes (4)	7905	1.7
Carytown	McIntosh	Carytown silt loam, 1-3% slopes, eroded (5)	6270	1.4
Carytown	McIntosh	Carytown - Burwell cmpx, 0-3% slopes (6)	2025	0.4
Carytown	Osage	Dennis - Carytown cmpx, 1-5% slopes (17)	43981	3.0
Carytown	Osage	Parsons - Carytown cmpx, 0-3% slopes (49)	22009	1.5
Carytown	Pottawatomie	Carytown silt loam, 0-1% slopes (5)	1290	0.3
Carytown	Seminole	Okemah - Carytown cmpx, 0-2% slopes (32)	1720	0.4
Carytown	Tulsa	Dennis - Carytown cmpx, 1-3% slopes (15)	20485	5.4
Carytown	Tulsa	Okemax - Parsons - Carytown cmpx, 0-1% slope (44)	28310	7.5
Doolin	Cleveland	Doolin - urban land - Pawhuska cmpx (49)	5575	1.6
Doolin	Cleveland	Doolin silt loam (50)	6129	1.7
Doolin	Cleveland	Doolin - Pawhuska cmpx (51)	3857	1.1
Doolin	Payne	Doolin silt loam, 0-2% slopes (96)	4025	0.9
Drummond	Alfalfa	Brewer - Drummond cmpx (Bu)	7630	1.4
Drummond	Alfalfa	Drummond soils	2685	0.5
Drummond	Alfalfa	Drummond - Pratt cmpx	1470	0.3
Drummond	Canadian	Brewer - Drummond cmpx (Bu)	3500	0.6
Drummond	Garfield	Drummond soils (Dr)	3803	0.6
Drummond	Grant	Drummond loam, saline, rarely flooded (8)	2026	0.3
Drummond	Grant	McLain - Drummond silt loams, rarely flooded (35)	23986	3.7
Drummond	Kingfisher	Drummond soils (Dr)	400	0.1
Drummond	Osage	Mason - Drummond cmpx, 0-1% slopes (33)	4643	0.3
Drummond	Noble	Calumet - Drummond silt loams, 0-1% slopes (Ca)	2724	0.5

Table 2. Soil mapping units containing sodic soils in Oklahoma Counties. (con=t.)[1]

SERIES	COUNTY	MAP UNIT NAME & CODE	ACRES	%[1]
Dwight	Okmulgee	Dwight - Parsons silt loams, 0-1% slopes (DwA)	3690	0.8
Dwight	Osage	Apperson - Dwight cmpx, 0-3% slopes (2)	27424	1.9
Dwight	Osage	Wolco - Dwight cmpx, 0-3% slopes	20844	1.4
Dwight	Pittsburg	Dennis - Dwight cmpx, 2-5% slopes, severely eroded (Dn3)	24765	2.8
Dwight	Pittsburg	Parsons - Dwight cmpx, 1-3% slopes, eroded (PdB2)	6725	0.8
Dwight	Pontotoc	Dwight silt loam, 0-1% slopes (DwA)	3153	0.7
Dwight	Rogers	Dwight silt loam, 0-1% slopes (DwA)	460	0.1
Dwight	Washington	Dwight - Parsons silt loams, 0-1% slope (DwA)	1360	0.5
Foard	Caddo	Foard silt loam, 0-1% slopes (FoA)	7010	0.9
Foard	Comanche	Foard silt loam, 0-1% slopes (FoA)	14305	2.1
Foard	Comanche	Foard and Tillman sails, 1-3% slopes (FtB)	81926	11.9
Foard	Comanche	Foard slickspots cmpx, 0-1% slopes (FsA)	3955	0.6
Foard	Comanche	Foard slickspots cmpx, 1-3% slopes (FsB)	23836	3.4
Foard	Comanche	Lawton - Foard cmpx, 3-5% slope (LfC)	1676	0.2
Foard	Cotton	Foard silt loam, 0-1% slopes (FoA)	50277	12.5
Foard	Cotton	Foard - slickspots cmpx, 0-1% slopes (FsA)	6221	1.5
Foard	Cotton	Foard - slickspots cmpx, 1-3% slopes (FsB)	12933	3.2
Foard	Cotton	Foard & Tillman silt loams, 1-3% slopes (FtB)	58844	14.6
Foard	Kiowa	Foard silt loam, 0-1% slopes (FdA)	25500	3.8
Foard	Tillman	Foard silt loam, 0-1 slopes (FdA)	21000	3.8
Foard	Tillman	Foard - Hinkle cmpx, 0-1% slopes (FhA)	28200	5.1
Foard	Tillman	Tillman & Foard soils, 1-3% slopes (TfB)	42300	7.7
Foard	Woods	Foard clay loam	9935	NA
Healdton	Carter	Healdton silt loam (15)	3286	0.6
Hinkle	Canadian	Grant - Hinkle cmpx, 1-3% slopes (GhB)	6400	1.2
Hinkle	Canadian	Kirkland - Hinkle cmpx, 0-3% slopes (KsB)	2900	0.5
Hinkle	Kiowa	Carey - Hinkle cmpx, 1-5% slopes (CbD)	3320	0.5
Hinkle	Kiowa	St-Paul - Hinkle cmpx, 0-1% slopes (SbA)	2850	0.4
Hinkle	Kiowa	Tillman - Hinkle cmpx, 1-3% slopes (TdB)	24250	3.7

Table 2. Soil mapping units containing sodic soils in Oklahoma Counties. (cont.)[1]

SERIES	COUNTY	MAP UNIT NAME & CODE	ACRES	%[1]
Hinkle	Tillman	Foard - Hinkle cmpx, 0-1% slopes (FhA)	28200	5.1
Hinkle	Tillman	St. Paul - Hinkle cmpx, 0-1% slopes (StA)	1400	0.3
Hinkle	Tillman	St. Paul - Hinkle cmpx, 1-3% slopes (StB)	5400	1.0
Hinkle	Tillman	Tillman - Hinkle cmpx, 1-3% slopes (ThB)	31400	5.7
Hinkle	Grady	Renfrow - Hinkle cmpx, 1-3% slopes	2580	0.4
Huska	Cleveland	Renfrow - Huska cmpx, 1-5% slopes, eroded (65)	10038	2.8
Huska	Cleveland	Renfrow - Huska cmpx, 1-5% slopes (66)	5003	1.4
Huska	Cleveland	Renfrow - Urban land-Huska cmpx, 1-5% slopes (69)	1972	0.6
Huska	Cleveland	Grant - Huska cmpx, 1-5% slopes (84)	6083	1.7
Huska	Cleveland	Grant - Urban land-Huska cmpx, 1-5% slopes (88)	271	0.1
Huska	Payne	Zaneis - Huska cmpx, 1-5% slopes (71)	10215	2.3
Huska	Payne	Huska silt loam, 1-3% slopes (81)	4385	1.0
Lafe	Sequoyah	Lafe soils (La)	1895	0.4
Oscar	Grant	Oscar - Grant cmpx, frequently flooded, 0-12% slope (38)	5188	0.8
Oscar	Jefferson	Port - Oscar cmpx (Po)	33543	7.0
Oscar	Payne	Port - Oscar cmpx, occassionally flooded (39)	460	0.1
Oscar	Tillman	Ashport - Oscar cmpx	700	0.1
Pawhuska	Cleveland	Doolin - Urban land-Pawhuska cmpx, 0-3% slopes (149)	5575	1.6
Pawhuska	Cleveland	Doolin - Pawhuska cmpx, 0-3% slopes (51)	3857	1.1
Pawhuska	Cleveland	Bethany - Pawhuska cmpx, 0-3% slopes (52)	807	0.2
Pawhuska	Cleveland	Doolin - Pawhuska cmpx, 0-3% slopes eroded (53)	5308	1.5
Pawhuska	Grant	Kirkland - Pawhuska silt loams, 0-2% slopes (31)	13346	2.1
Pawhuska	Grant	Renfrow - Pawhuska cmpx, 2-5% slopes, eroded (50)	3713	0.6
Pawhuska	McClain	Bethany - Pawhuska cmpx, 0-2% slopes	1485	0.4
Pawhuska	Osage	Corbin - Pawhuska cmpx, 1-5% slopes (12)	24256	1.6
Pawhuska	Osage	Norge - Pawhuska cmpx, 1-5% slopes (43)	17120	1.2
Seminole	Payne	Seminole loam, 0-2% slopes (78)	2365	0.5
Seminole	Payne	Seminole loam, 2-5% slopes, eroded (79)	870	0.2
Seminole	Pottawatomie	Seminole loam, 0-2% slopes (39)	1760	0.3

Table 2. Soil mapping units containing sodic soils in Oklahoma Counties. (con=t.)[1]

SERIES	COUNTY	MAP UNIT NAME & CODE	ACRES	%[1]
Seminole	Pottawatomie	Seminole loam, 2-5% slopes (40)	6420	1.2
Seminole	Seminole	Seminole loam, 1-3% slopes (37)	3605	0.9
Seminole	Seminole	Seminole loam, 2-5% slopes, eroded (38)	19855	4.9
Seminole	Seminole	Seminole, Chiskasha, and Prue soils, 2-8% slopes, severely eroded (39)	27700	6.1
Seminole	Seminole	Seminole-Gowton cmpx, 0-12% slopes (40)	11880	2.9
Wakita	Grant	Kingfisher-Wakita silt loams, 1-3% slopes (27)	4914	0.8
Wakita	Grant	Kingfisher-Wakita silt loams, 2-5% slopes eroded (28)	2234	0.3
Wing	Caddo	Grant-Wing cmpx, 1-5% slopes (GwC)	2810	0.3
Wing	Haskell	Counts-Wing cmpx, 1-3% slopes (CwB)	8612	2.3
Wing	Jefferson	Zaneis-Wing cmpx, 0-3% slopes (ZwB)	138355	28.6
Wing	Latimer	Counts-Wing cmpx, 1-3% slopes (18)	1905	0.4
Wing	LeFlore	Wing silt loam, 0-2% slopes (82)	8559	0.9
Wing	Haskell	Counts-Wing cmpx, 1-3% slopes (CwB)	8612	2.3
Wister	Latimer	Wister silt loam, 1- 3% slope (46)	3710	0.8
Wister	LeFlore	Wister silt loam, 0-1% slopes (83)	1172	0.1
Wister	LeFlore	Wister silt loam, 1-3% slopes (84)	23362	2.3
Wister	LeFlore	Wister silt loam, 3-5% slopes (85)	1974	0.2
Slickspots	Comanche	Foard - slickspots cmpx, 0-1% slopes (FsA)	3955	0.6
Slickspots	Comanche	Foard - slickspots cmpx, 1-3% slopes (FsB)	23836	3.4
Slickspots	Comanche	Port - slickspots cmpx (Ps)	9361	1.3
Slickspots	Comanche	Zaneis - slickspots cmpx, 1-3% slopes (ZsB)	33403	4.9
Slickspots	Comanche	Slickspots	4938	0.7
Slickspots	Garfield	Kirkland - slickspots cmpx, 0-1% slopes (KsA)	5056	0.7
Slickspots	Garfield	Miller-slickspots cmpx (Ms)	2358	0.3
Slickspots	Garfield	Reinach - slickspots cmpx (Re)	1653	0.2
Slickspots	Hughes	Okemah - slickspots cmpx, 1-3% slopes (OkB)	8650	1.7
Slickspots	Hughes	Okemah - slickspots cmpx, 1-3% slopes, eroded (OkB2)	1680	0.3
Slickspots	Cotton	Foard - slickspots cmpx, 0-1% slopes (FsA)	6221	1.5

Table 2. Soil mapping units containing sodic soils in Oklahoma Counties. (con=t.)[1]

SERIES	COUNTY	MAP UNIT NAME & CODE	ACRES	%[1]
Slickspots	Cotton	Foard - slickspots cmpx, 1-3% slopes (FsB)	12933	3.2
Slickspots	Cotton	Port - slickspots cmpx, (1Ps)	12947	3.2
Slickspots	Cotton	Zaneis - slickspots cmpx, 1-3% sl (ZsB)	27213	6.8
Slickspots	Kingfisher	Kingfisher - slickspots cmpx, 1-3% slopes (KhB)	2700	0.5
Slickspots	Kingfisher	Kingfisher - slickspots cmpx, 3-5% slopes (KhC)	1200	0.2
Slickspots	Kingfisher	Norge - slickspots cmpx, 1-3% slopes (NsB)	5900	1.0
Slickspots	Kingfisher	Norge - slickspots cmpx, 3-5% slopes, eroded (NsC3)	600	0.1
Slickspots	Kingfisher	Tabler - slickspots cmpx, (Ts)	2300	0.4
Slickspots	Kay	Lafette - slickspots cmpx, 3-5% slopes, eroded (L6C2)	1560	0.3
Slickspots	Kay	Lela - slickspots cmpx (Le)	2670	0.4
Slickspots	Blaine	Kingfisher - slickspots cmpx, 1-3% slopes (KIB)	1850	0.3
Slickspots	Blaine	Lela, - wet slickspots cmpx	1300	0.2
Slickspots	Blaine	Leshara - slickspots cmpx	2250	0.4
Slickspots	Love	Slickspots & saline land (Se)	1617	0.5
Slickspots	Oklahoma	Norge - slickspots cmpx, 0-3% slopes (NsB)	600	0.1
Slickspots	Oklahoma	Renfrow - slickspots cmpx, 1-3% slopes, eroded (RsB2)	800	0.2
Natrustalf	Kiowa	Natrustalf	1000	0.1
Oil-Waste lands	Noble	Oil waste land (OA)	1394	0.3
Oil-Waste lands	Carter	Oil-Waste lands (33)	4647	0.1
Oil-Waste lands	Creek	Oil-Waste lands (Oa)	4500	0.7
Oil-Waste lands	Garvin	Oil-Waste lands (55)	324	0.1
Oil-Waste lands	Muskogee	Oil-Waste lands (43)	525	0.1
Oil-Waste lands	Okmulgee	Oil-Waste lands (Od)	1712	0.4
Oil-Waste lands	Nowata	Oil-Waste lands (Ow)	300	0.1
Oil-Waste lands	Payne	Oil-Waste lands (99)	240	0.1
Oil-Waste lands	Osage	Oil-Waste lands (44)	1927	0.1
Oil-Waste lands	Stephens	Oil-Waste lands (Ow)	1138	0.2
Oil-Waste lands	Seminole	Oil-Waste lands (29)	660	0.2
Oil-Waste lands	Tulsa	Oil-Waste lands (38)	395	0.1

Table 2. Soil mapping units containing sodic soils in Oklahoma Counties. (con=t.)[1]

SERIES	COUNTY	MAP UNIT NAME & CODE	ACRES	%[1]
Oil-Waste lands	Washington	Oil-Waste lands (Od)	2180	0.8
Oil-Waste lands	Hughes	Oil-Waste lands (Od)	675	0.1
Oil-Waste lands	Kay	Oil-Waste lands (Od)	1970	0.3
Badland	Beckham	Badland	4796	0.8

[1]Logan, Jackson and Okfuskee counties contain sodic soils. Revised soil surveys yet to be published.

[1]NA – not available

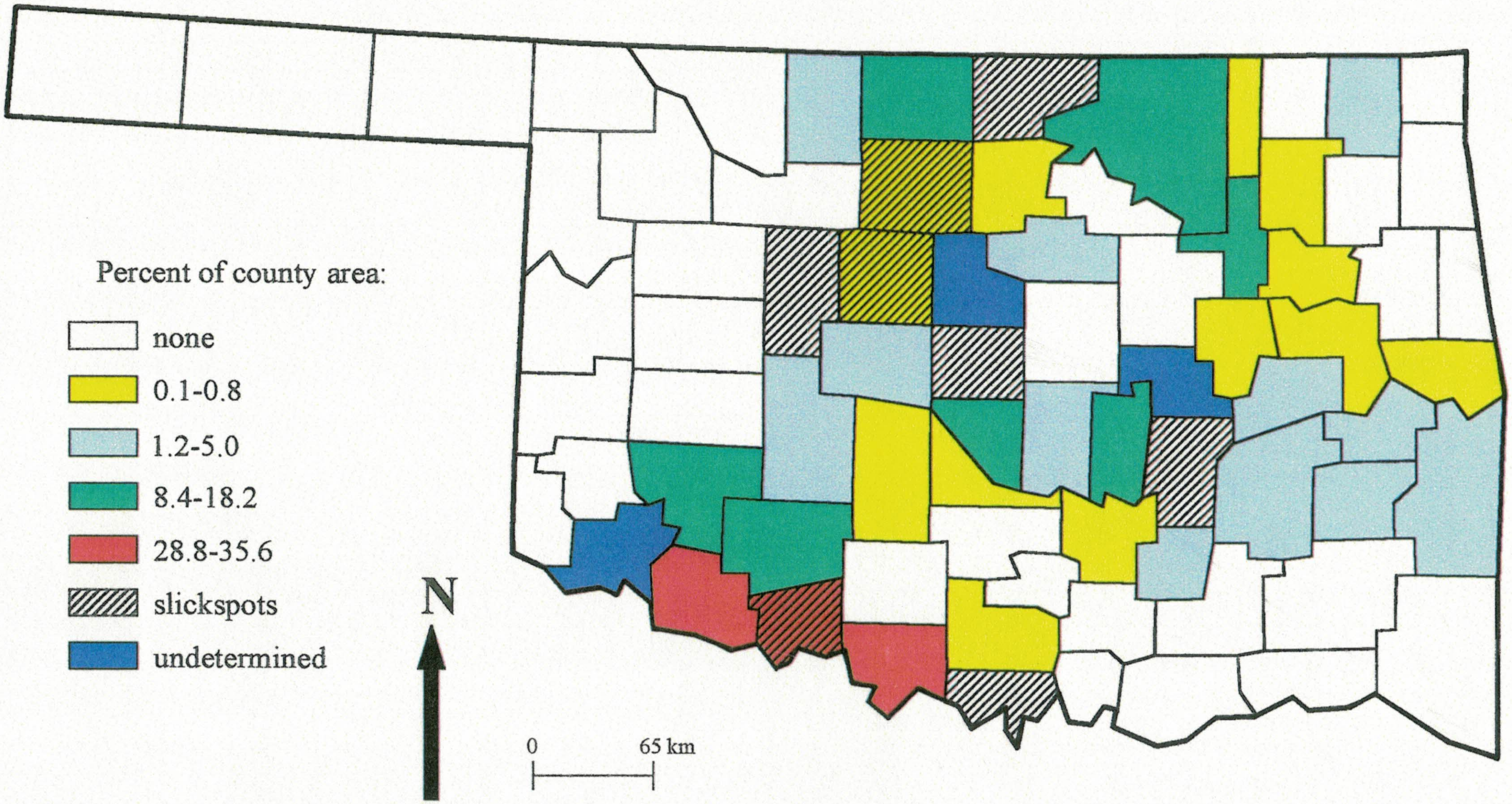


Figure 2. The approximate area of sodic-dispersive (natric) soils in Oklahoma counties taken from USDA/NRCS county soil surveys.

Table 3. Parent materials and landscape positions of natric (sodic) soils in Oklahoma

Soil Series	Landscape Position	Parent Material
Bonn	stream terrace/floodplains	loess and/or alluvium
Carytown	upland	alluvium/residuum (shale)/colluvium/loess
Doolin	stream terrace	alluvium/sandstone
Drummond	stream terrace/floodplain	alluvium
Dwight	upland	loess/alluvium/shale
Foard	upland/stream terrace	alluvium/shale
Healdton	floodplain	alluvium
Hinkle	upland/stream terrace	alluvium
Huska	upland	shale/sandstone
Lafe	stream terrace	loess/alluvium
Oscar	floodplain	alluvium
Pawhuska	upland	shale/sandstone/loamy or clayey alluvium
Seminole	upland	shale/loamy or clayey alluvium
Wakita	sideslope	shale/sandstone
Wing	upland/stream terrace	residuum/colluvium/alluvium
Wister	upland	shale

Table 4. Drainage and depth of sodic soils in Oklahoma.

Soil Series	Drainage[H]	Depth to rock
Bonn	poorly – drained	deep (greater than 150 cm)
Carytown	poorly – drained	deep (greater than 150 cm)
Doolin	well – drained	deep (greater than 150 cm)
Drummond	somewhat poorly - drained	deep (greater than 150 cm)
Dwight	mod. well - drained	deep (greater than 150 cm)
Foard	mod. well - drained	deep (greater than 150 cm)
Healdton	somewhat poorly - drained	deep (greater than 150 cm)
Hinkle	mod. well - drained	deep (greater than 150 cm)
Huska	mod. well - drained	deep (greater than 150 cm)
Lafe	somewhat poorly - drained	deep (greater than 150 cm)
Oscar	mod. well - drained	deep (greater than 150 cm)
Pawhuska	mod. well - drained	deep (greater than 150 cm)
Seminole	mod. well - drained	deep (greater than 150 cm)
Wakita	mod. well - drained	mod. deep (100 - 150 cm)
Wing	mod. well - drained	deep (greater than 150 cm)
Wister	mod. well - drained	deep (greater than 150 cm)

[H]mod. is moderately

Table 5. Taxonomic classification of sampled soils based on data from the study.

Site #	Soil Series	Taxonomic classification based on data from the study	Sampled as: Soil Series (County)	Sampled as: Previous Taxonomic classification
1	Cadeville	Fine, mixed, thermic Albaquic Hapludalf	Bosville (Choctaw)	Fine, mixed, thermic Albaquic Paleudalfs
2	No known series	Fine-silty, mixed, thermic Aquollic Hapludalf	Dwight (Pittsburg)	Fine, smectitic, mesic Typic Natrustolls
3	No known series	Fine, kaolinitic, thermic Typic Natrudalf	Wing (Le Flore)	Fine, mixed, thermic Aquic Natrustalfs
4	No known series	Very fine, vermiculitic, thermic Typic Hapludalf	Wister (Le Flore)	Fine, mixed, thermic Vertic Natrudalfs
5	No known series	Fine, mixed, thermic Typic Natrustalf	Pawhuska (McClain)	Fine, mixed, thermic Mollic Natrustalfs
6	No known series	Fine, mixed, thermic Glossaquic Natrudalf□	Lafe (Sequoyah)	Fine-silty, mixed, thermic Glossic Natrudalfs
7	Counts	Fine, mixed, thermic Albaquic Paleudalf	Carytown (Muskogee)	Fine, mixed, thermic Albic Natraqualfs
8	Mason	Fine-silty, mixed, thermic Pachic Argiudoll	Dwight (Okmulgee)	Fine, smectitic, mesic Typic Natrustolls
9	No known series	Fine, mixed*, thermic Typic Natrustalf□	Doolin (Cleveland)	Fine, smectitic, thermic Typic Natrustolls
10	No known series	Fine, mixed*, thermic Vertic Natrustoll	Drummond (Canadian)	Fine, mixed, thermic Mollic Natrustalfs
11	No known series	Fine, mixed, thermic Typic Natrustoll□	Dwight (Osage)	Fine, smectitic, mesic Typic Natrustolls
12	No known series	Fine-silty, mixed, thermic Typic Natrustoll	Drummond (Grant)	Fine, mixed, thermic Mollic Natrustalfs
13	Zaneis	Fine-loamy, siliceous*, thermic Udic Argiustoll□	Huska (Payne)	Fine, mixed, thermic Mollic Natrustalfs

Table 5. Taxonomic classification of sampled soils based on data from the study. (con't.)

Site #	Soil Series	Taxonomic classification based on data from the study	Sampled as	
			Soil Series (County)	Taxonomic classification
14	Doolin	Fine, smectitic*, thermic Typic Natrustolls□	Doolin (Payne)	Fine, smectitic, thermic Typic Natrustolls
15	No known series	Fine, vermiculitic, thermic Typic Natrudoll	Carytown (Tulsa)	Fine, mixed, thermic Albic Natraqualfs
16	Seminole#	Fine, mixed*, thermic Typic Natrustoll	Seminole (Payne)	Fine, mixed, thermic Typic Natrustoll
17	No known series	Fine, mixed*, thermic Typic Natrustalf	Healdton (Carter)	Fine, mixed, thermic Vertic Natraqualfs
18	No known series	Fine-loamy, mixed, thermic Typic Natrustalf	Wing (Jefferson)	Fine, mixed, thermic Aquic Natrustalfs
19	No known series	Fine-loamy, mixed, thermic Typic Natrustalf	Oscar (Jefferson)	Fine-silty, mixed, thermic Typic Natrustalfs
20	No known series	Fine, mixed*, thermic Leptic Natrustalf	Foard (Comanche)	Fine, smectitic, thermic Vertic Natrustolls
21	Oscar	Fine-silty, mixed*, thermic Typic Natrustalf	Oscar (Tillman)	Fine-silty, mixed, thermic Typic Natrustalfs
22	No known series	Fine, smectitic, thermic Typic Natrustoll	Hinkle (Kiowa)	Fine, smectitic, thermic Vertic Natrustalfs
23	Oscar##	Fine-silty, mixed*, thermic Typic Natrustalf	Hinkle (Grady)	Fine, smectitic, thermic Vertic Natrustalfs

- The soil is Seminole if lower B had 35-50% clay
- The soil is Oscar if C had 24-35% clay
* - Mineralogy class is assumed

However, these soils had dispersive horizons (greater than 30% dispersion based on double-hydrometer test). Natric (sodic) soils (as classified by Soil Survey Staff, 1999) also had one or more horizons that were not dispersive. Thus, current soil taxonomy cannot be used to infer engineering capabilities of these soils.

The soil sampled in Zaneis-Huska complex as Huska (Site 13, Payne Co.) was Zaneis (Fine-loamy, siliceous, thermic Udic Argiustoll) (Table 5), which is not natric (sodic). The distribution of sodic soils in complexes with other non-sodic soils has not been determined (see Geographic Distribution of Sodic Soils section, p. 25). Site specific soil information must be collected to determine areas of sodic soils in complexes with non-sodic soils.

SALIENT FIELD MORPHOLOGIC CRITERIA FOR IDENTIFICATION OF SODIC SOILS

Lack of Columnar Structure

A salient field criteria used by soil scientists to identify sodic soils is columnar soil structure at the top of the B horizon (upper subsoil). Only 2 of 23 sodic soils sampled exhibited this columnar structure. The soils with columnar structure are in native pastures which haven't been disturbed by tillage. All other soils contained recent (within several years) evidence of plowing for agricultural production. Lack of columnar structure in most sodic soils suggest 1) that columnar structure is destroyed by surface tillage, 2) that columnar structure in sodic soils occurs where these soil surface horizons are pristine, and 3) columnar structure should not be used to identify all sodic soils.

Siltans Identify Most Sodic Conditions

A salient field criteria which was present in the majority of sodic soils sampled was gray accumulations (often referred to as cutans, "tans") of silt particles (silt; "sil" plus "tans" equals siltans) as a "skin" along the walls of prismatic soil structure of the upper subsoil (B horizon). The siltans accumulate where water flow is concentrated along soil pores or walls and are accentuated by the dispersion of soil particles in sodic soils. Siltans are a better field morphologic indicator of sodic soil conditions compared to identification of columnar structure.

Natric Horizon Identification

All soils contained more illuviated clay in the subsoil (B horizon) compared to the surface horizon (A horizon) (Table 6). When there is a clayey B horizon and it also contains sodium and is dispersive these soils are termed natric. Natric horizons are slowly permeable to water. The soils sampled in this study contained redoximorphic features including mottles and

Table 6. Range for clay content and bulk density for soils in the study.

Site #	Soil Series (county sampled)	% clay (less than 0.002 mm) Range for B horizon	A horizon	bulk density (g/cm^3) B horizon
1	Bosville (Choctaw)	30.1 – 43.6	6.4	1.71 - 1.83
2	Dwight (Pittsburg)	32.6 – 46.7	21.5	1.64 – 1.88
3	Wing (Leflore)	43.6 – 47.9	13.3	1.77 – 1.95
4	Wister (Leflore)	51.0 – 72.9	16.0	1.54 – 1.88
5	Pawhuska (McClain)	37.3 – 46.0	18.2	1.51 – 1.72
6	Lafe (Sequoyah)	38.5 – 42.6	18.3	1.75 – 1.93
7	Carytown (Muskogee)	36.9 – 43.9	11.9	1.52 – 1.89
8	Dwight (Okmulgee)	26.8 – 33.6	11.3	1.15 – 1.51
9	Doolin (Cleveland)	37.8 – 42.1	12.9	1.71 – 2.00
10	Drummond (Canadian)	23.3 – 55.8	31.5	1.79 – 1.82
11	Dwight (Osage)	44.2 – 55.5	33.7	1.79 – 1.82
12	Drummond (Grant)	29.3 – 40.2	30.0	1.41 – 1.76
13	Huska (Payne)	26.7 – 30.6	15.4	1.62 – 1.88
14	Doolin (Payne)	27.2 – 42.6	11.3	1.52 – 1.91
15	Carytown (Tulsa)	27.3 – 48.0	16.3	1.79 – 1.94
16	Seminole (Payne)	20.3 – 41.8	17.5	1.61 – 1.87
17	Healdton (Carter)	42.1 – 49.5	11.3	1.83 – 2.06
18	Wing (Jefferson)	20.8 - 34.0	9.4	1.86 – 1.99
19	Oscar (Jefferson)	22.1 – 24.4	16.5	1.60 – 1.99
20	Foard (Comanche)	40.6 – 45.1	19.6	1.74 – 1.78
21	Oscar (Tillman)	25.6 – 41.1	19.2	1.73 – 1.86
22	Hinkle (Kiowa)	23.8 – 52.9	19.3	1.62 – 1.84
23	Hinkle (Grady)	28.2 – 35.3	15.9	1.90 – 2.08
	mean	32.0 – 44.2		

iron-manganese concretions. These redoximorphic features indicate soil horizons with slow permeabilities which are produced from soil sodicity.

Parent Material and Landscape Position

Parent materials of the sodic soils sampled are listed in Table 7. Most of the soils (17 out of 23) were formed in alluvium (unconsolidated material), mainly in stream deposits. Beneath the alluvium Pennsylvanian or Permian rock occurred in eastern and western Oklahoma, respectively. Several sodic soils (Wister in LeFlore Co., Dwight in Okmulgee Co., Dwight in Osage Co., Huska in Payne Co., Wing in Jefferson Co., Hinkle in Grady Co.) were formed in residuum (sedimentary rock, consolidated material) – shale, sandstone, or limestone (Table 7). Soils were on nearly level or gently sloping uplands, terraces, or floodplains. Sodic soils are dispersive and easily eroded. Sodic soils persist on relatively level landscapes that are less susceptible to erosion compared to steeper slopes where they are probably naturally excluded.

Table 7. Parent Materials of Soils Sampled for ODOT Item #2140-Dispersive Soils.

Site No.	Soil mapping unit	County	Parent material	Geologic formation	Equivalents	Group	Epoch*	Period*	Era*	Geologic formation of underlying rock unit	Equivalents	Group	Epoch*	Period*	Era*
1	Bosville sandy loam, 1-4% slopes	Choctaw	alluvium	Unnamed-high terrace deposits			Pl	Q	C	Grayson shale	Dakota Sandstone	Washita	Comanche	Cr	M
2	Parsons-Dwight complex, 1-3% slopes, eroded	Pittsburg	alluvium	Unnamed-high terrace deposits			Pl	Q	Q	Thurman sandstone		Cabaniss		Pn	P
3	Wing silt loam, 0-2% slope	Le Flore	alluvium	terrace deposits			H	Q	C	McAlester formation		Krebs		Pn	P
4	Wister silt loam, 0-1% slopes	Le Flore	residuum	McAlester formation		Krebs		Pn	P						
5	Bethany-Pawhuska complex, 0-3% slopes	McClain	alluvium	Unnamed-high terrace deposits			Pl	Q	C	Hennessey shale	Clear Fork Group (TX)			Pe	P
6	Lafe soils	Sequoyah	alluvium	Unnamed-low terrace deposits			H	Q	C	McAlester formation		Krebs		Pe	P
7	Parsons-Carytown silt loam, 0-1% slopes	Muskogee	alluvium	Unnamed-low terrace deposits			H	Q	C	Boggy formation		Krebs		Pe	P
8	Dwight-Parsons silt loams, 0-1% slopes	Okmulgee	residuum	Wewoka formation	Nowata shale	Marmaton		Pn	P						
9	Doolin-Pawhuska complex	Cleveland	alluvium	Unnamed-high terrace deposits			Pl	Q	C	Hennessey shale	Clear Fork Group (TX)			Pe	P
10	Brewer-Drummond complex	Canadian	alluvium	Unnamed-low terrace deposits			H	Q	C	Dog Creek shale		El Reno		Pe	P
11	Apperson-Dwight complex, 0-3% slopes	Osage	residuum	Red Eagle Limestone		Council Grove		Pn	P						
12	McClain-Drummond silt loams, rarely flooded	Grant	alluvium	Unnamed-low terrace deposits			H	Q	C	Garber sandstone				Pe	P
13	Huska silt loam, 1-3% slopes	Payne	residuum	Wellington Formation				Pe	P						

Table 7. Parent Materials of Soils Sampled for ODOT Item #2140-Dispersive Soils (cont.).

Site No.	Soil mapping unit	County	Parent material	Geologic formation	Equivalents	Group	Epoch*	Period*	Era*	Geologic formation of underlying rock unit	Equivalents	Group	Epoch*	Period*	Era*
14	Doolin silt loam	Payne	alluvium	Unnamed-high terrace deposits			Pl	Q	C	Neva limestone		Council Grove		Pe	P
15	Okemah-Parsons-Carytown complex, 0-1% slopes	Tulsa	alluvium	Unnamed-high terrace deposits			Pl	Q	C	Labette shale		Marmaton		Pn	P
16	Seminole loam, 0-2% slope	Payne	alluvium	Unnamed-low terrace deposits			H	Q	C	Vanoss and Ada formations	Wabaunsee group and upper part of Shawnee group (KS)	Pontotoc		Pn	P
17	Healdton silt loam	Carter	alluvium	Unnamed-low terrace deposits			H	Q	C	Vanoss formation	same	Pontotoc		Pn	P
18	Zaneis-Wing complex, 0-3% slopes	Jefferson	residuum	Wichita formation	Garber sandstone			Pe	P						
19	Port-Oscar complex	Jefferson	alluvium	Unnamed-low terrace deposits			H	Q	C	Wichita formation	Garber sandstone			Pe	P
20	Foard silt loam, 0-1% slopes	Comanche	alluvium	Unnamed-low terrace deposits			H	Q	C	Wichita formation	Garber sandstone			Pe	P
21	Asa-Oscar complex	Tillman	alluvium	Unnamed-low terrace deposits			H	Q	C	Wichita formation	Garber sandstone			Pe	P
22	St-Paul-Hinkle complex, 0-1% slopes	Kiowa	alluvium	Unnamed-high terrace deposits			Pl	Q	C	Wichita formation	Garber sandstone			Pe	P
23	Renfrow-Hinkle complex, 1-3% slopes	Grady	residuum	Dog Creek shale		El Reno		Pe	P						

*- C-Cenozoic, Cr-Cretaceous, H-Holocene, M-Mesozoic, P-Paleozoic, Pe-Permian, Pn - Pennsylvanian, Pl-Pleistocene, Q-Quaternary

GEOGRAPHIC DISTRIBUTION OF SODIC SOILS IN OKLAHOMA

USDA-NRCS County Soil Surveys

United States Department of Agriculture – Natural Resources Conservation Service county soil surveys were used to determine the geographic distribution of sodic soils in Oklahoma. These published hard-copy surveys are also available through the Department of Plant and Soil Sciences, Oklahoma State University as digitized computer generated maps. These digitized maps can overlay important geographic features (Digital Atlas of Oklahoma) to produce maps showing the distribution of sodic soils in specific counties (Figures 3-21). Maps showing distribution of sodic-dispersive hazards in Oklahoma were produced in MicroSoft ArcView Geographic Information System (GIS) software program (version 3.1) using digitized soil maps based on information taken from county soil surveys (USDA, NRCS) and the Digital Atlas of Oklahoma (software, compiled by United States Geological Survey, 1997).

County 1:24,000-scale maps of soil mapping units (USDA/NRCS county soil surveys) were digitized (200m X 200 m pixels) and converted into files compatible with the Digital Atlas of Oklahoma by Mark Gregory, Oklahoma State University GIS specialist. Minimum size delineation for 1:24,000-scale map is 2.3 hectares (Soil Survey Staff, 1993). The county soil map was superimposed on the corresponding county map from the Digital Atlas of Oklahoma including designations of rivers and roads. Scale, north arrow, and legend were added using standard procedure for making layouts in ArcView. The program allows the removal or addition of river, roadways, or soil mapping units. This option gives an opportunity to study the distribution and location of certain soil series or soil mapping units in relation to streams or road network. The Digital Atlas of Oklahoma also contains the township and range system, which aids in locating certain soil series or mapping unit on a map. The sodic-dispersive hazard maps

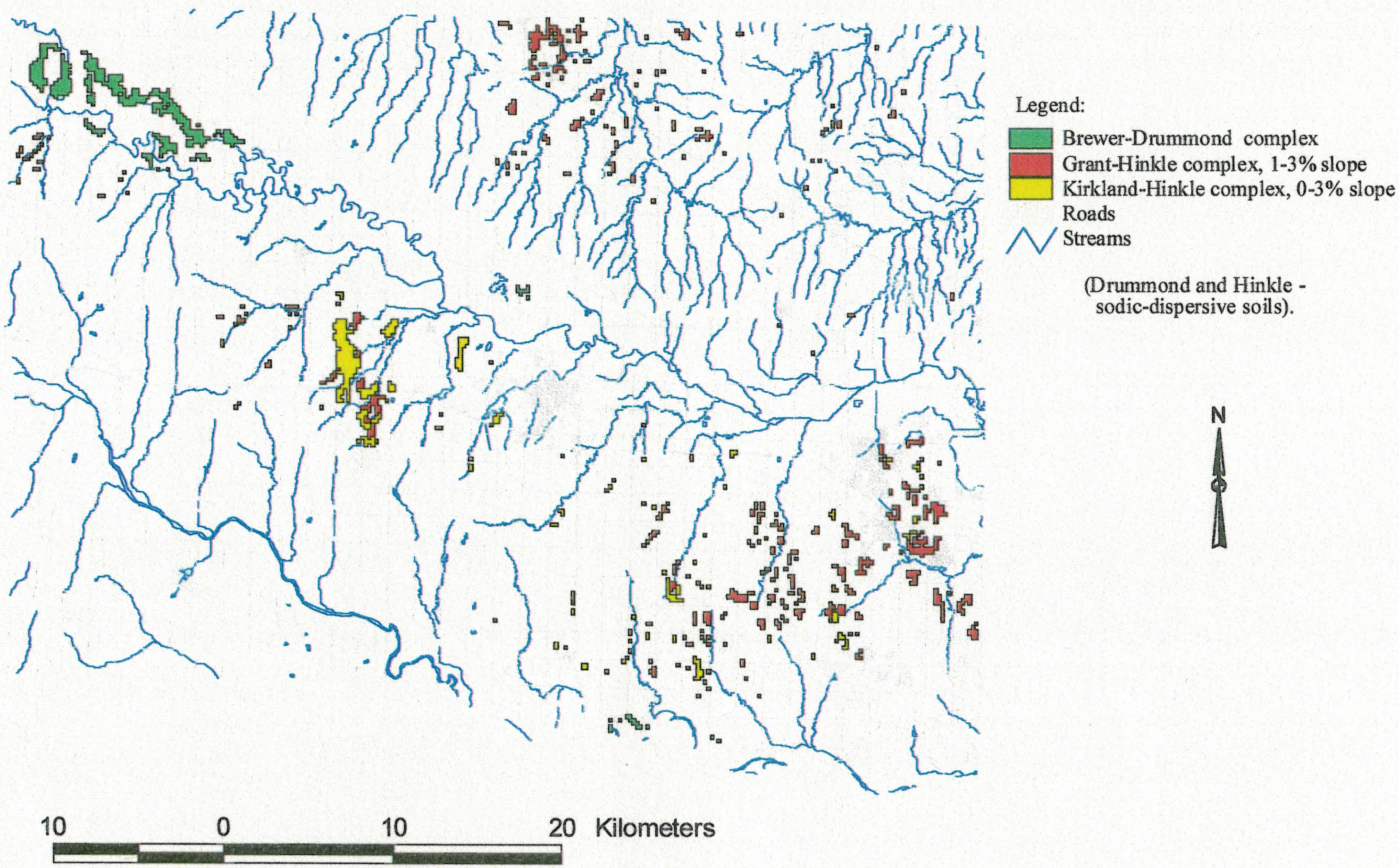


Figure 3. Sodic soils of Canadian County, Oklahoma, as identified by digitized county soil survey map (USDA/NRCS).

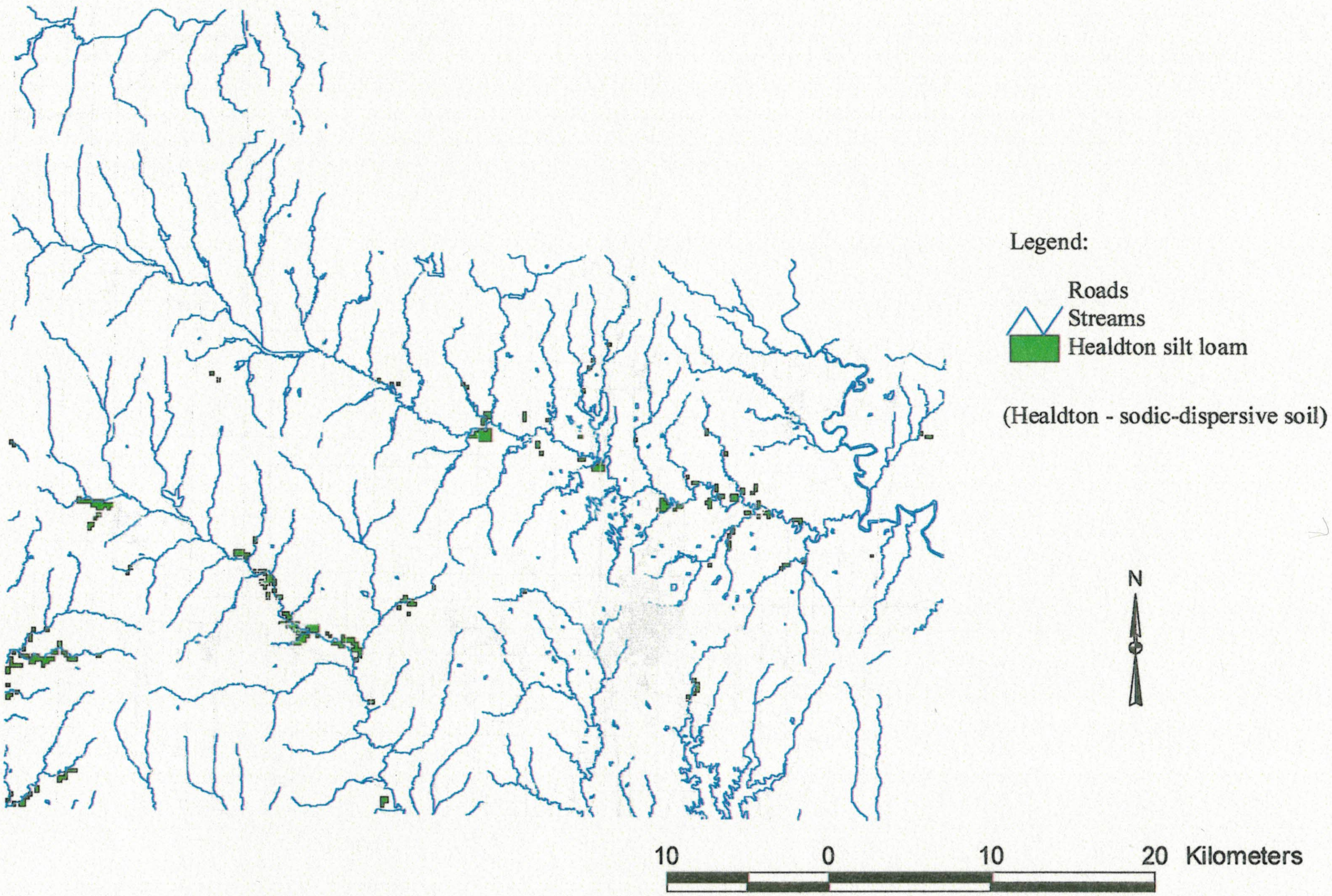


Figure 4. Sodic soils of Carter County, Oklahoma, as identified by digitized county soil survey map (USDA/NRCS).

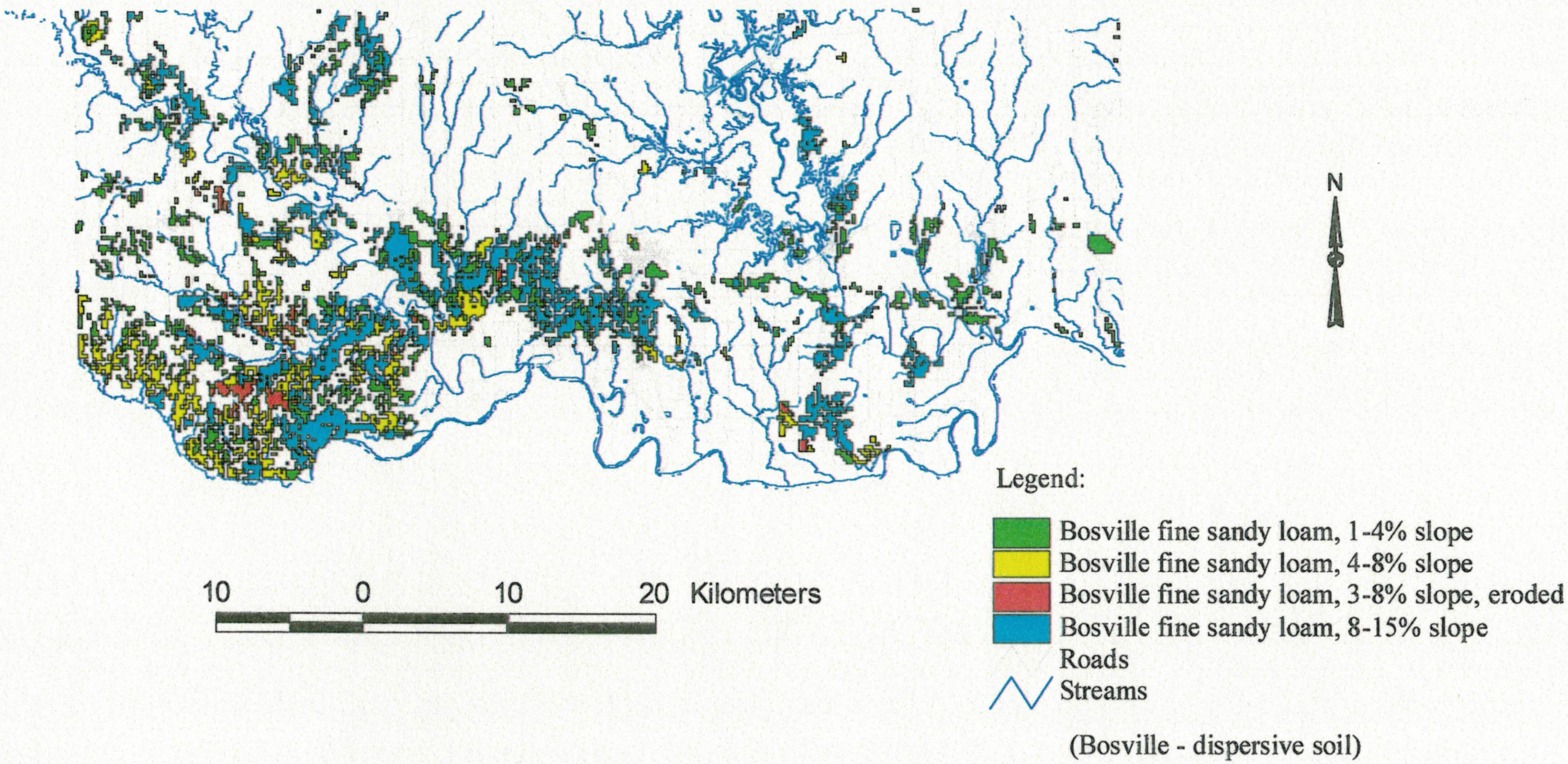


Figure 5. Dispersive soils of Choctaw County, Oklahoma, as identified by digitized county soil survey map (USDA/NRCS).

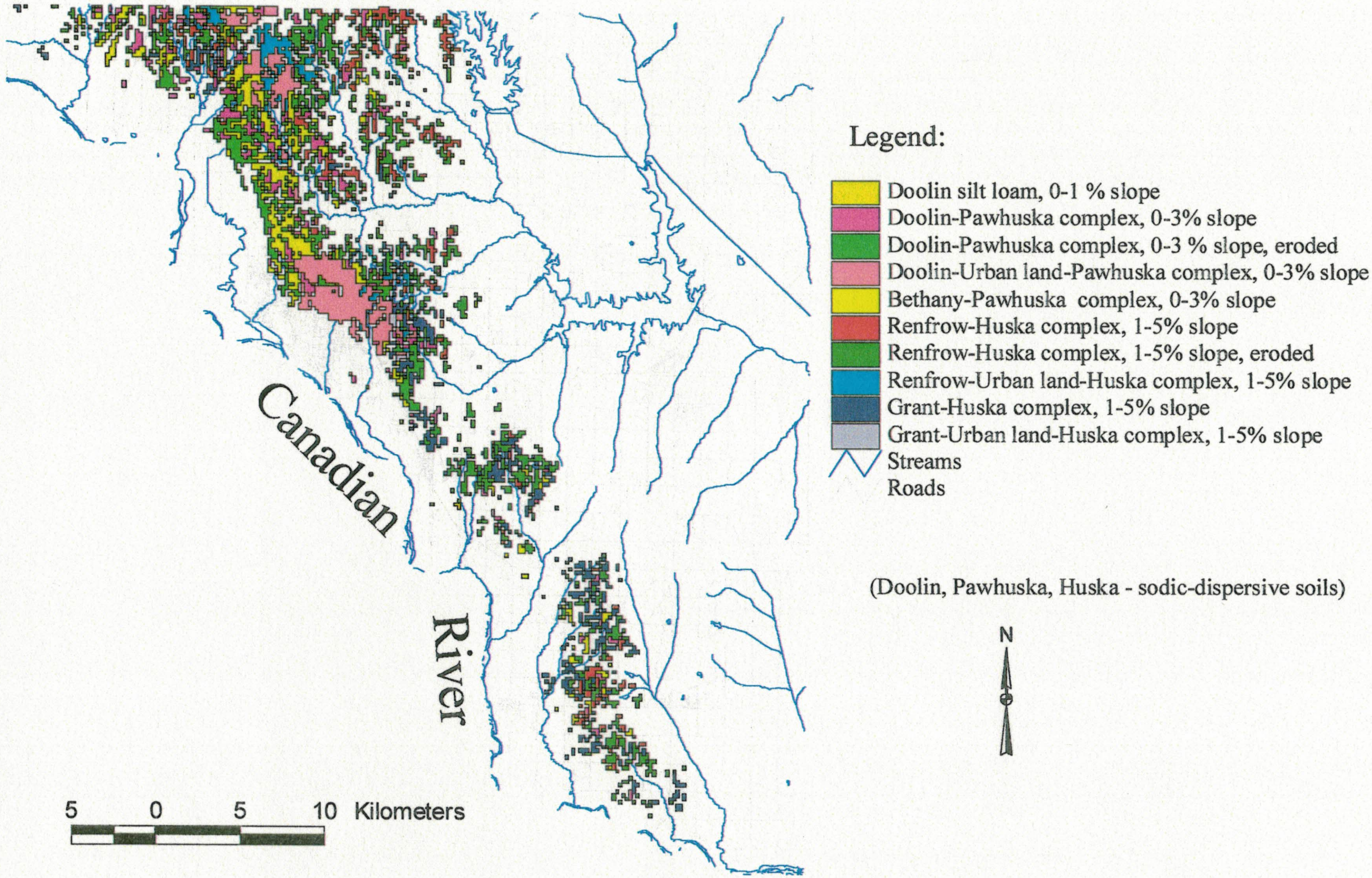


Figure 6. Sodic soils of Cleveland County, Oklahoma, as identified by digitized county soil survey map (USDA/NRCS).

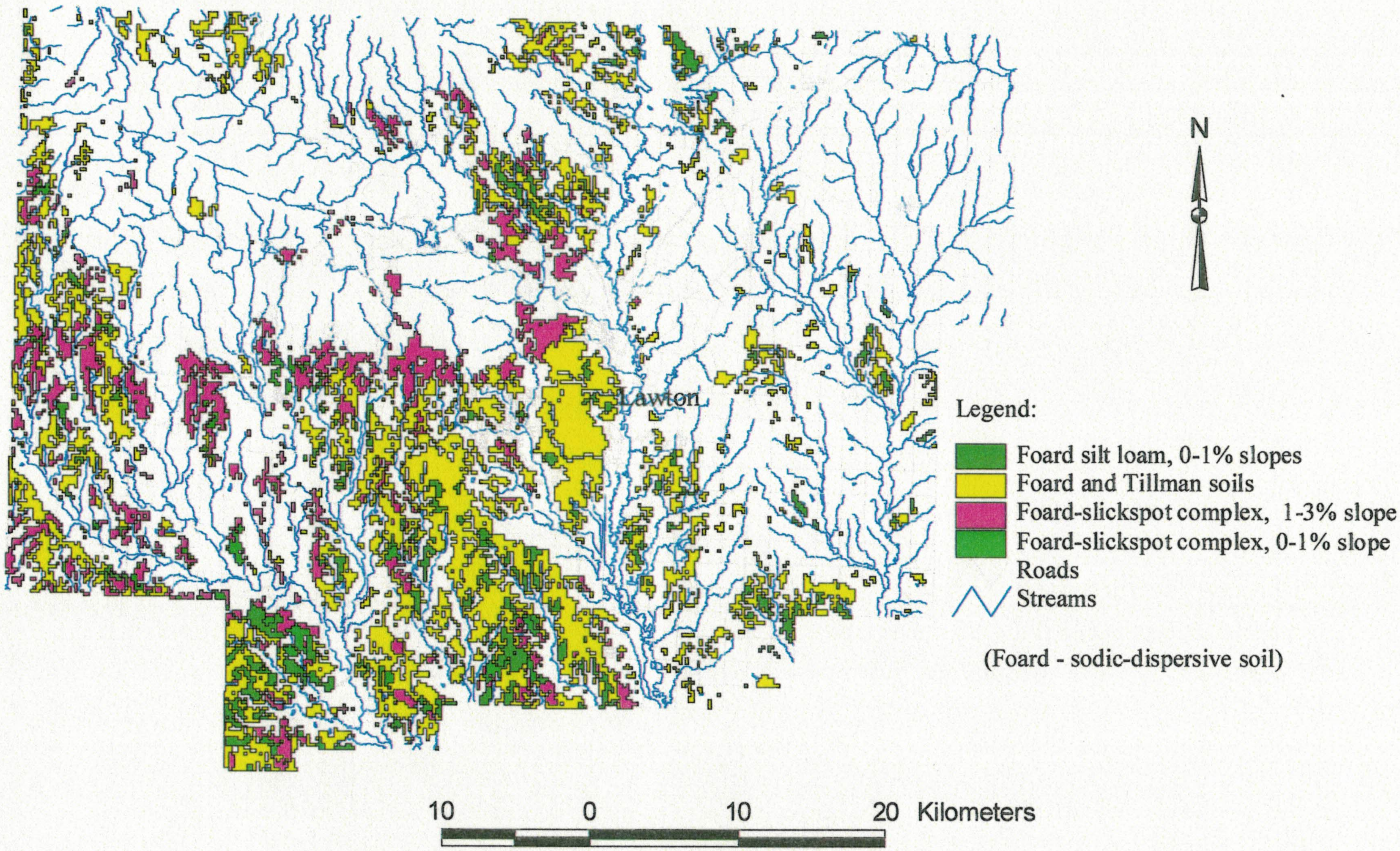


Figure 7. Sodic soils of Comanche County, Oklahoma, as identified by digitized county soil survey map (USDA/NRCS).

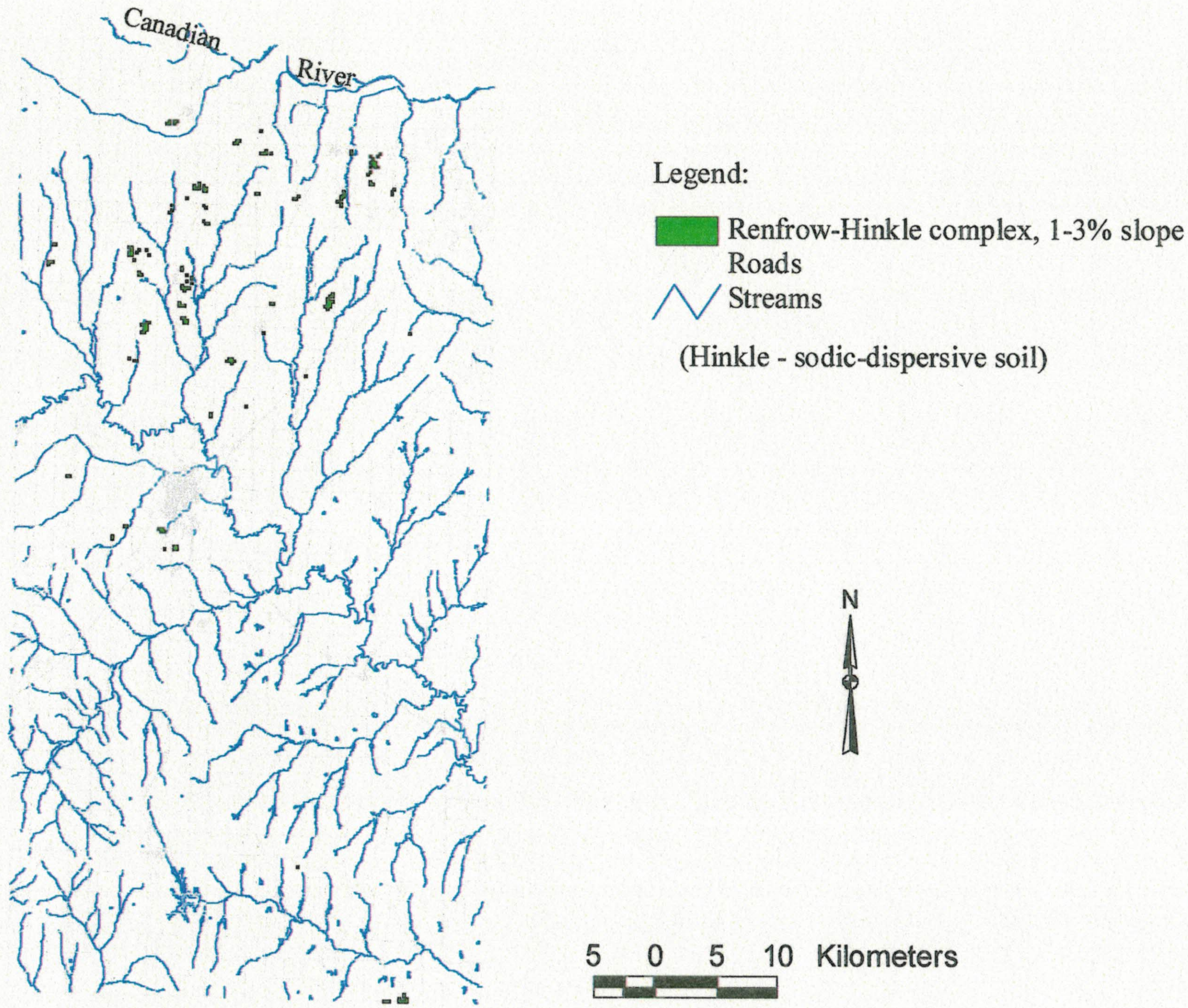


Figure 8. Sodic soils of Grady County, Oklahoma, as identified by digitized county soil survey map (USDA/NRCS).

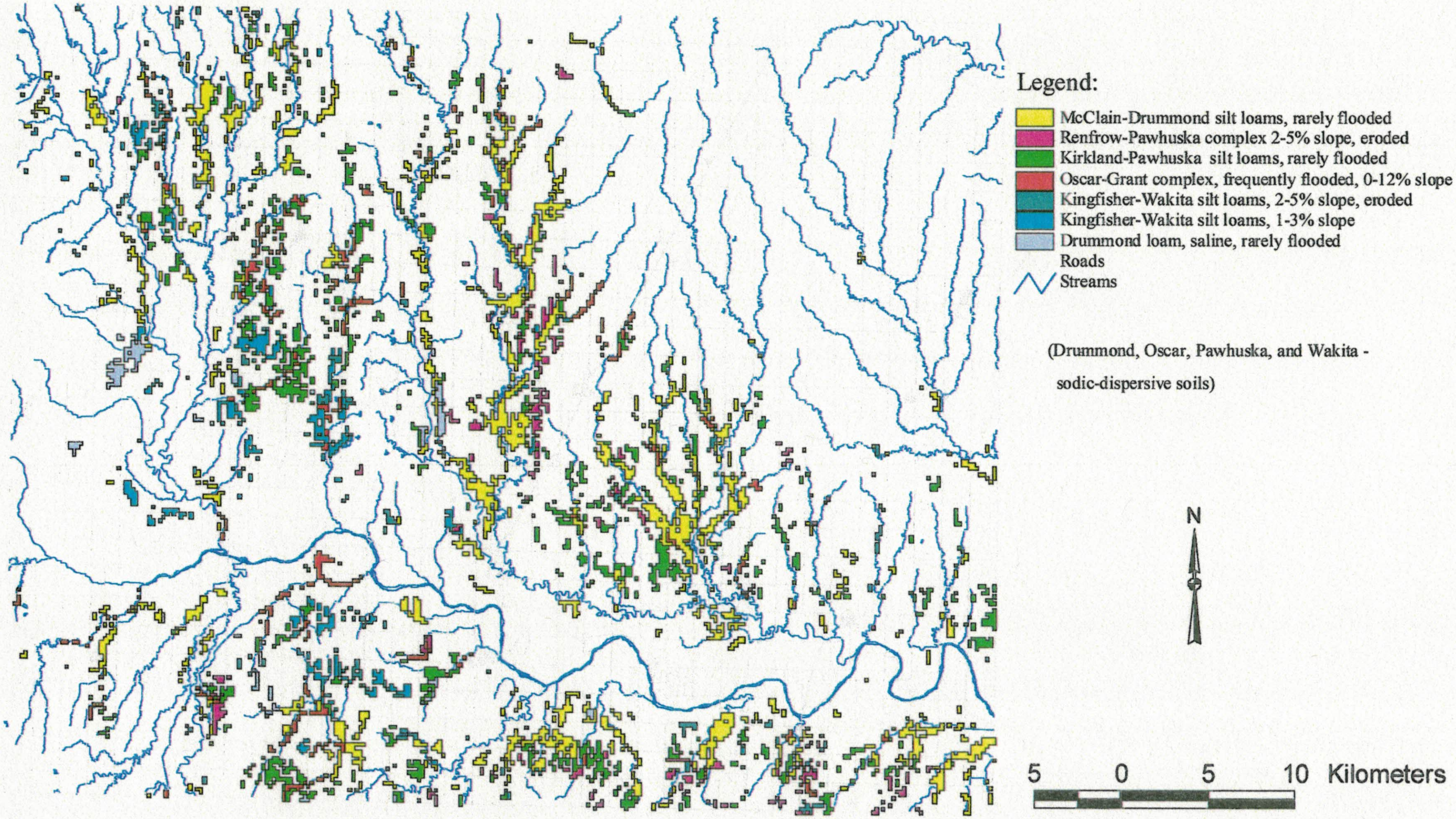


Figure 9. Sodic soils of Grant County, Oklahoma, as identified by digitized county soil survey map (USDA/NRCS).

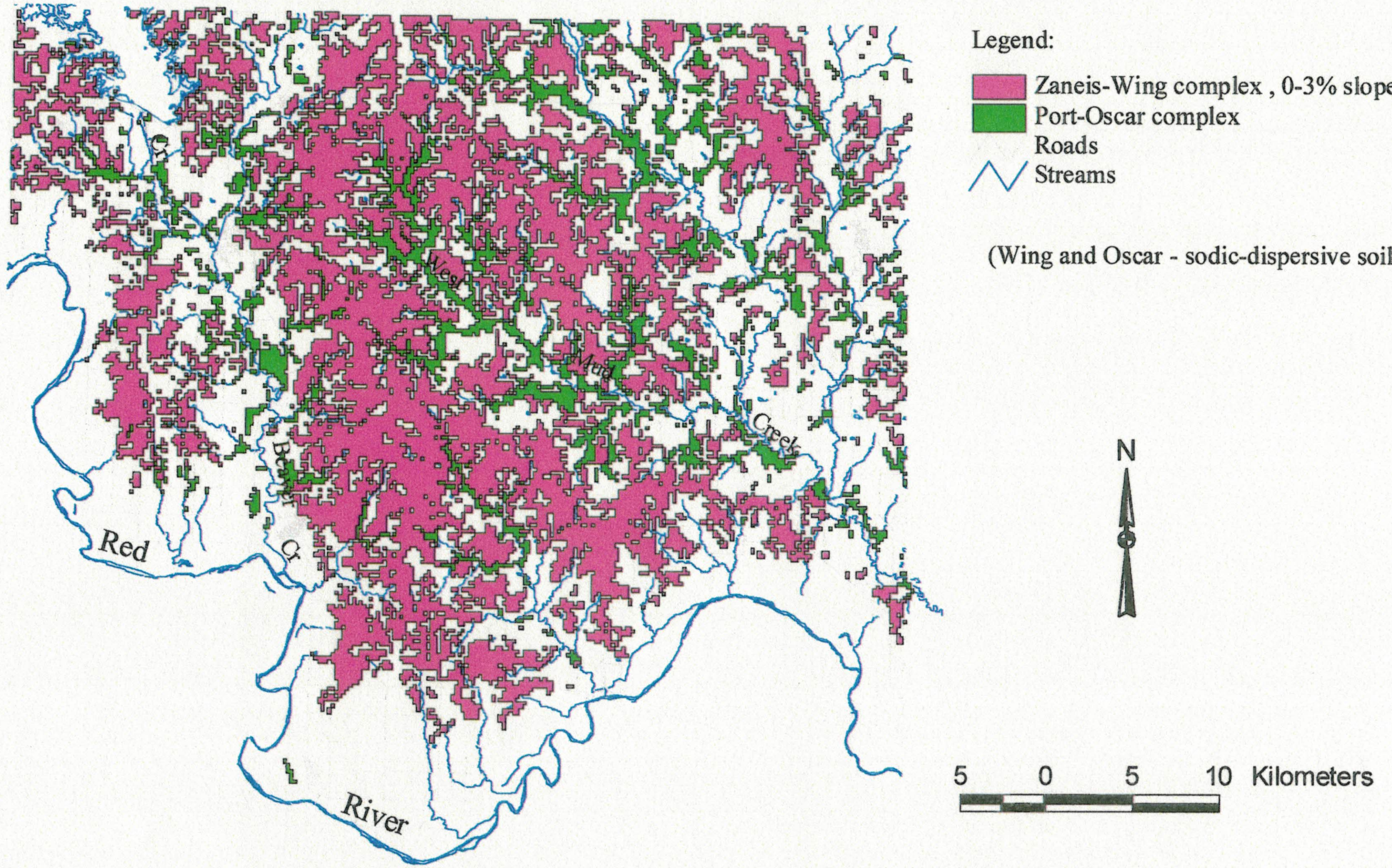


Figure 10. Sodic soils of Jefferson County, Oklahoma, as identified by county soil survey map (USDA/NRCS).

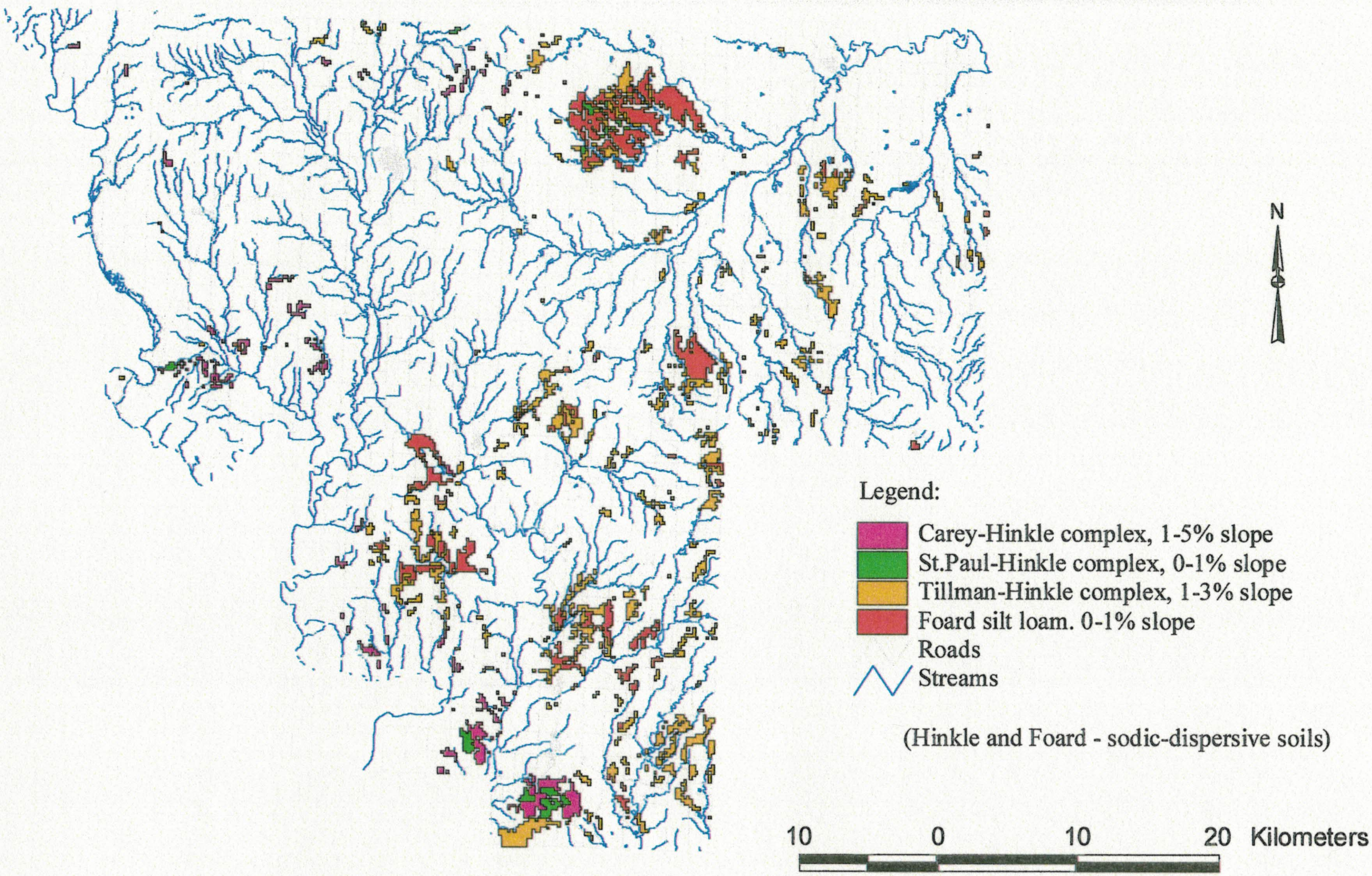


Figure 11. Sodic soils of Kiowa County, Oklahoma, as identified by digitized county soil survey map (USDA/NRCS).

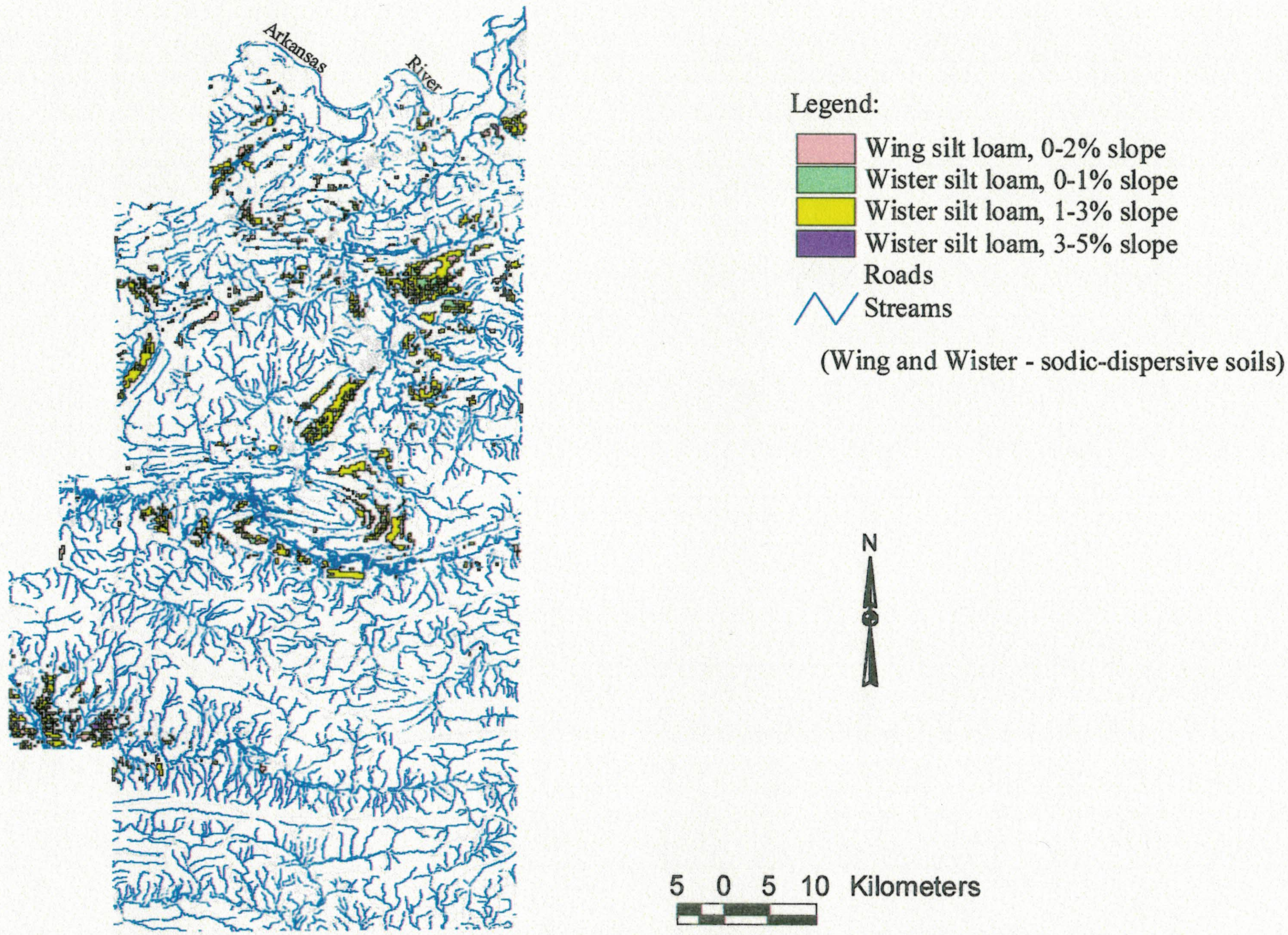


Figure 12. Sodic soils of LeFlore County, Oklahoma, as identified by digitized county soil survey map (USDA/NRCS).

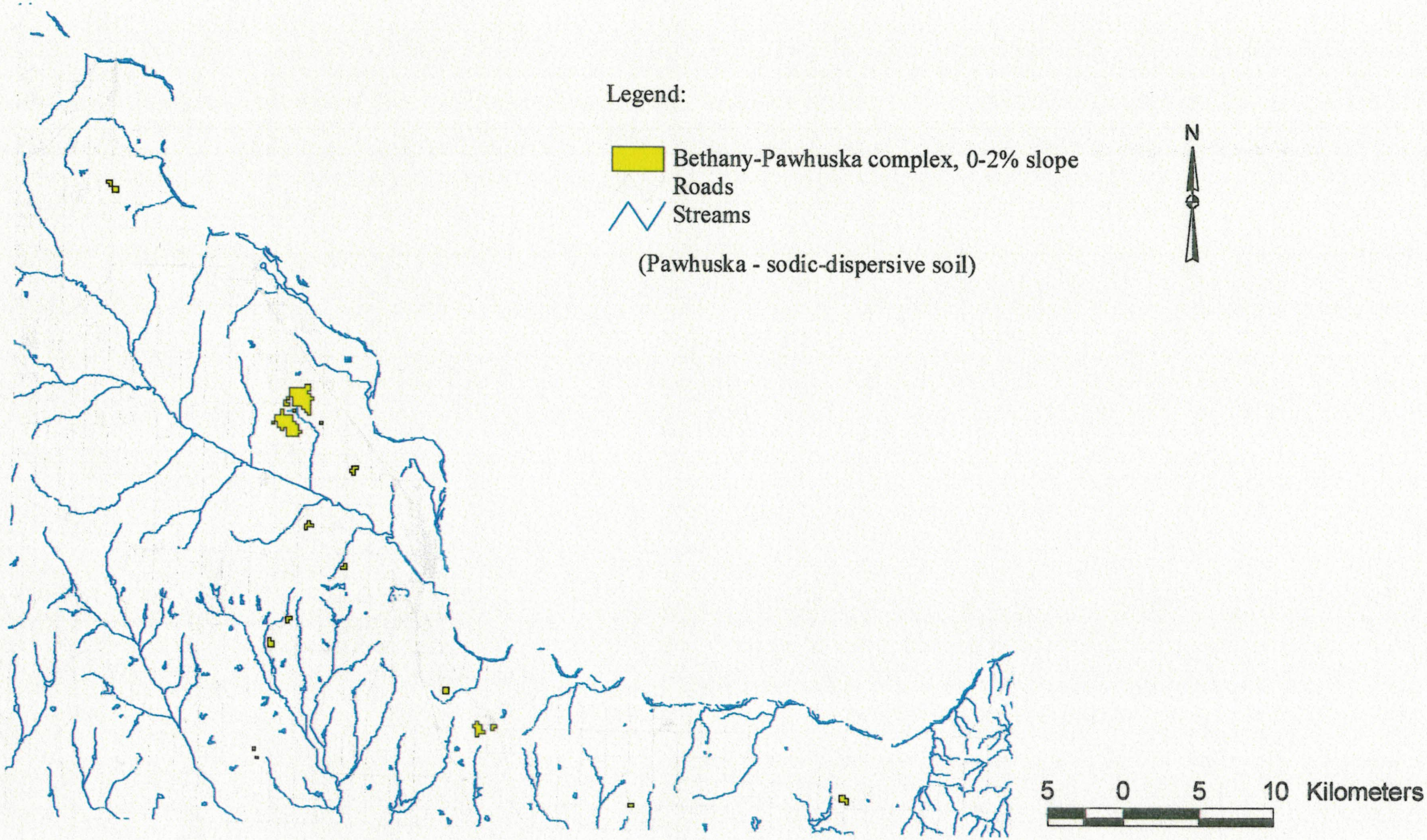


Figure 13. Sodic soils of McClain County, Oklahoma, as identified by digitized county soil survey map (USDA/NRCS).

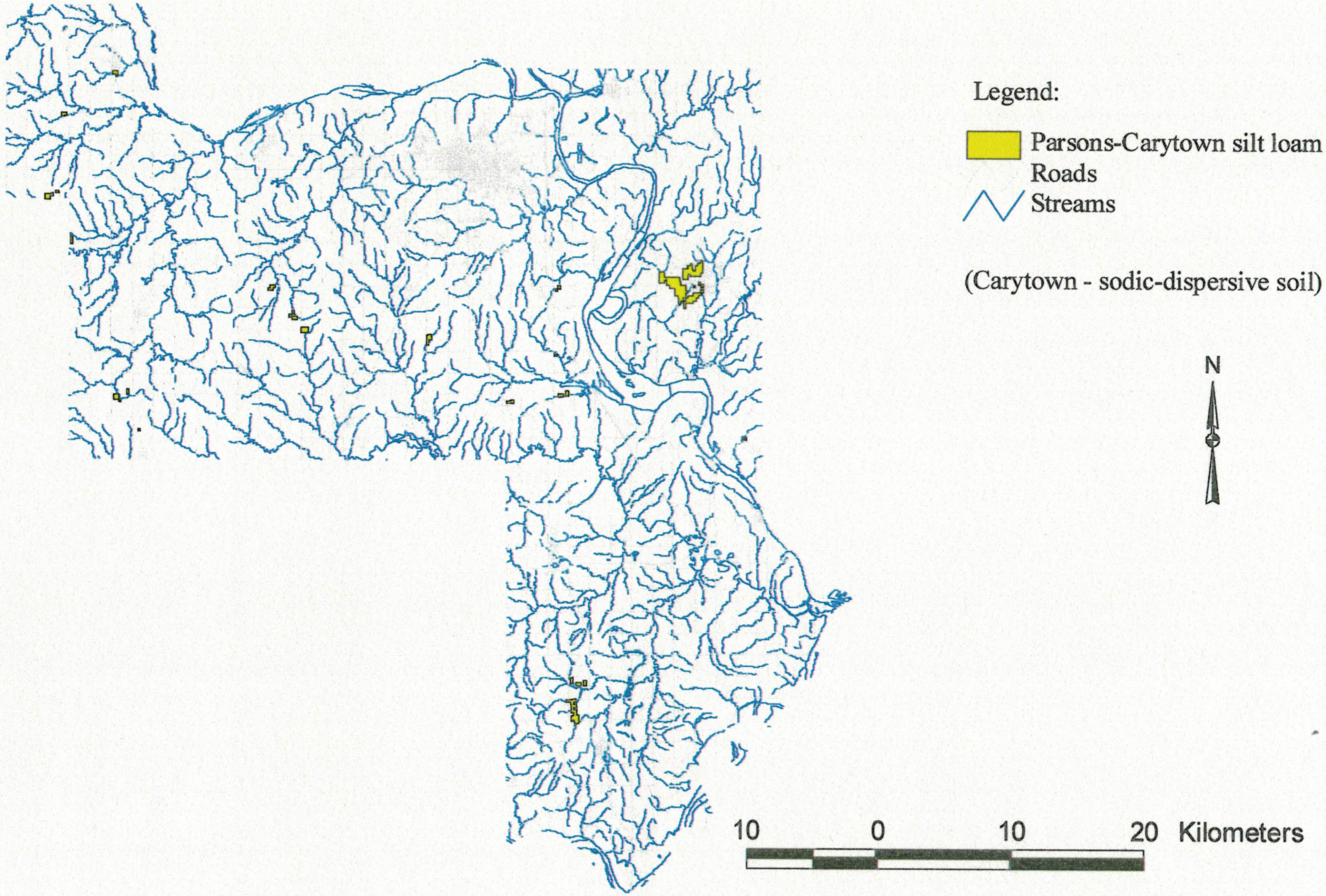


Figure 14. Sodic soils of Muskogee County, Oklahoma, as identified by digitized soil survey map (USDA/NRCS).

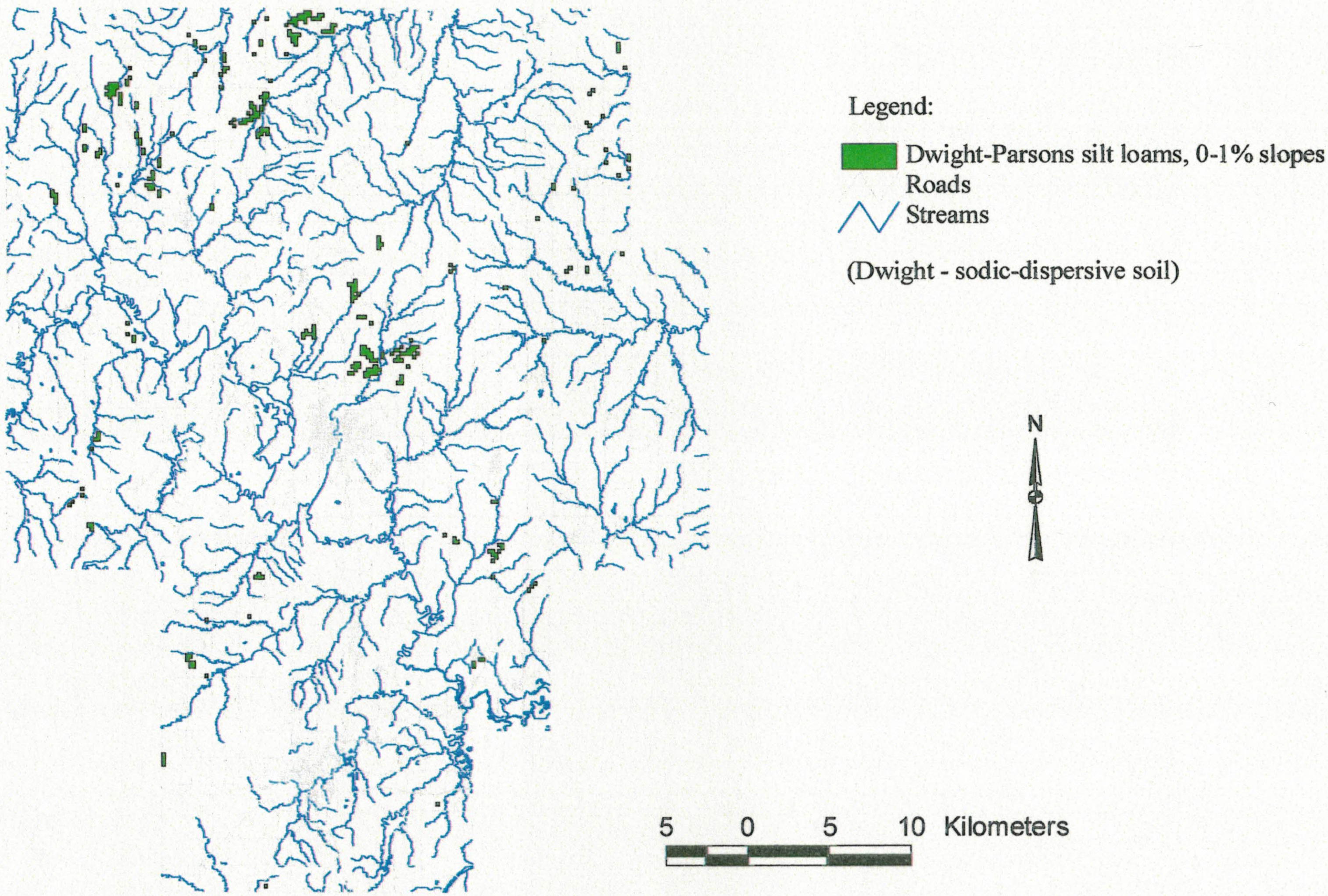


Figure 15. Sodic soils of Okmulgee County, Oklahoma, as identified by digitized county soil survey map (USDA/NRCS).

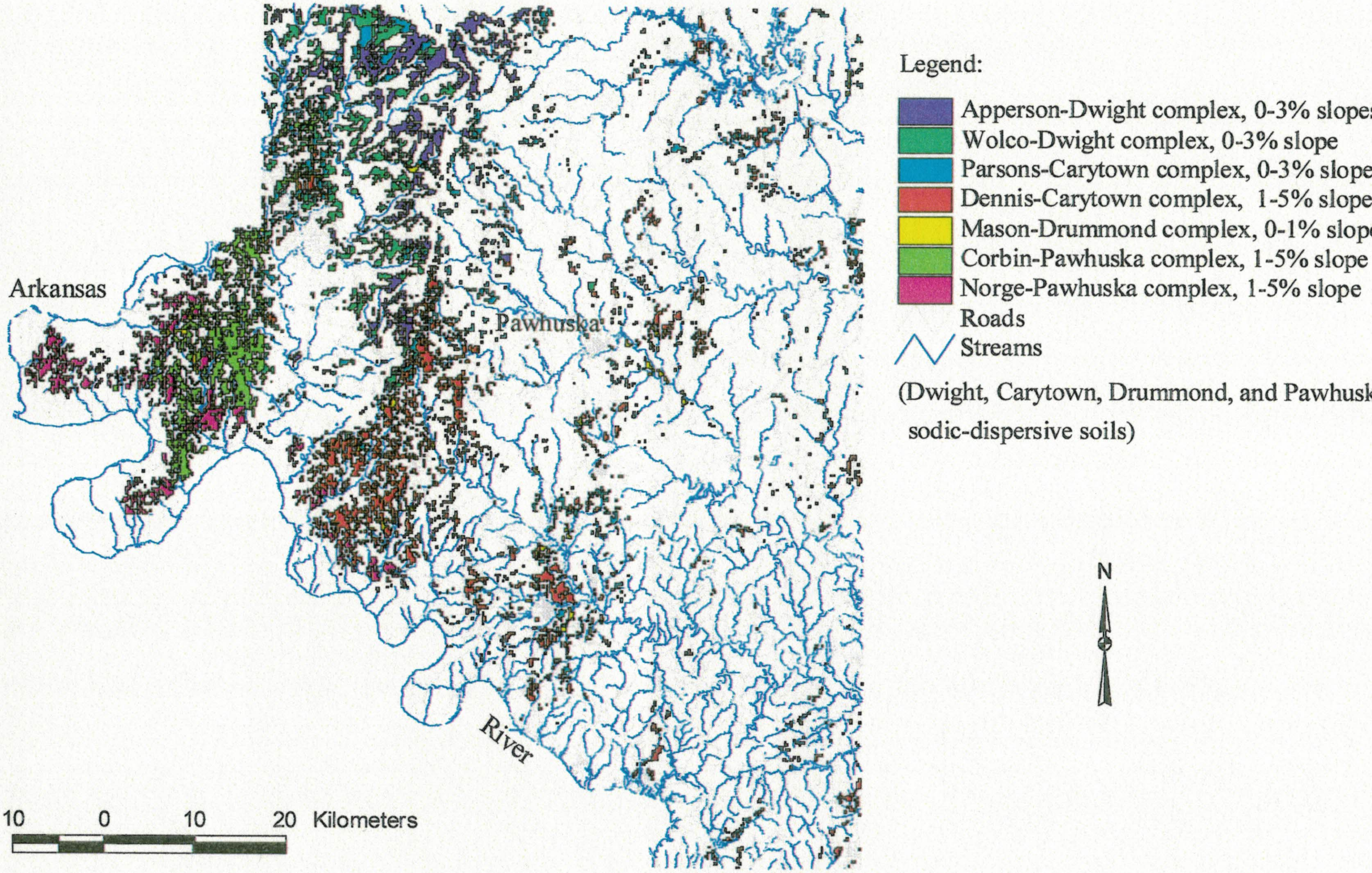
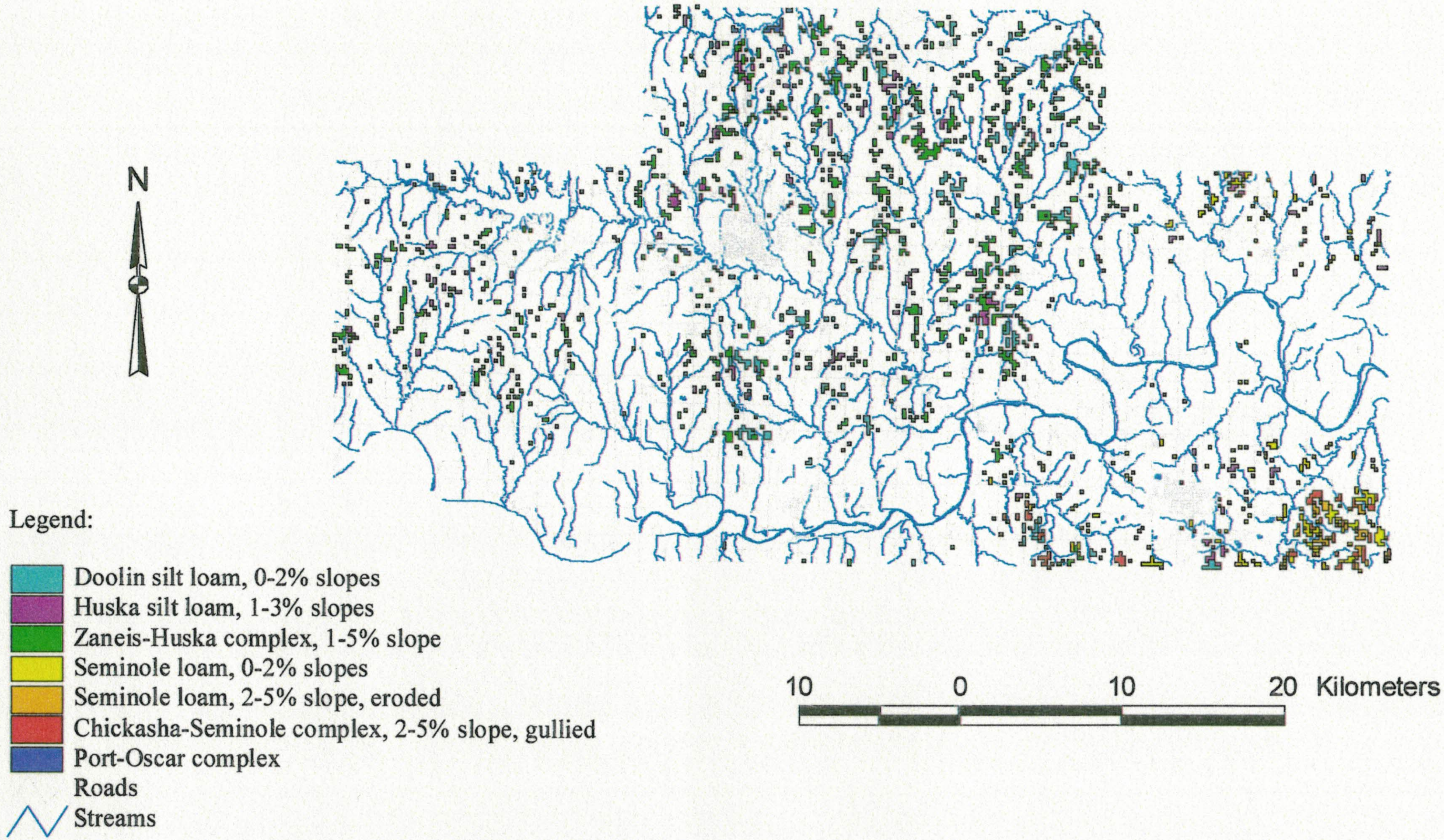


Figure 16. Sodic soils of Osage County, Oklahoma, as identified by digitized county soil survey map (USDA/NRCS).



(Doolin, Huska, Seminole, Oscar - sodic-dispersive soils)

Figure 17. Sodic soils of Payne County, Oklahoma, as identified by county soil survey map (USDA/NRCS).

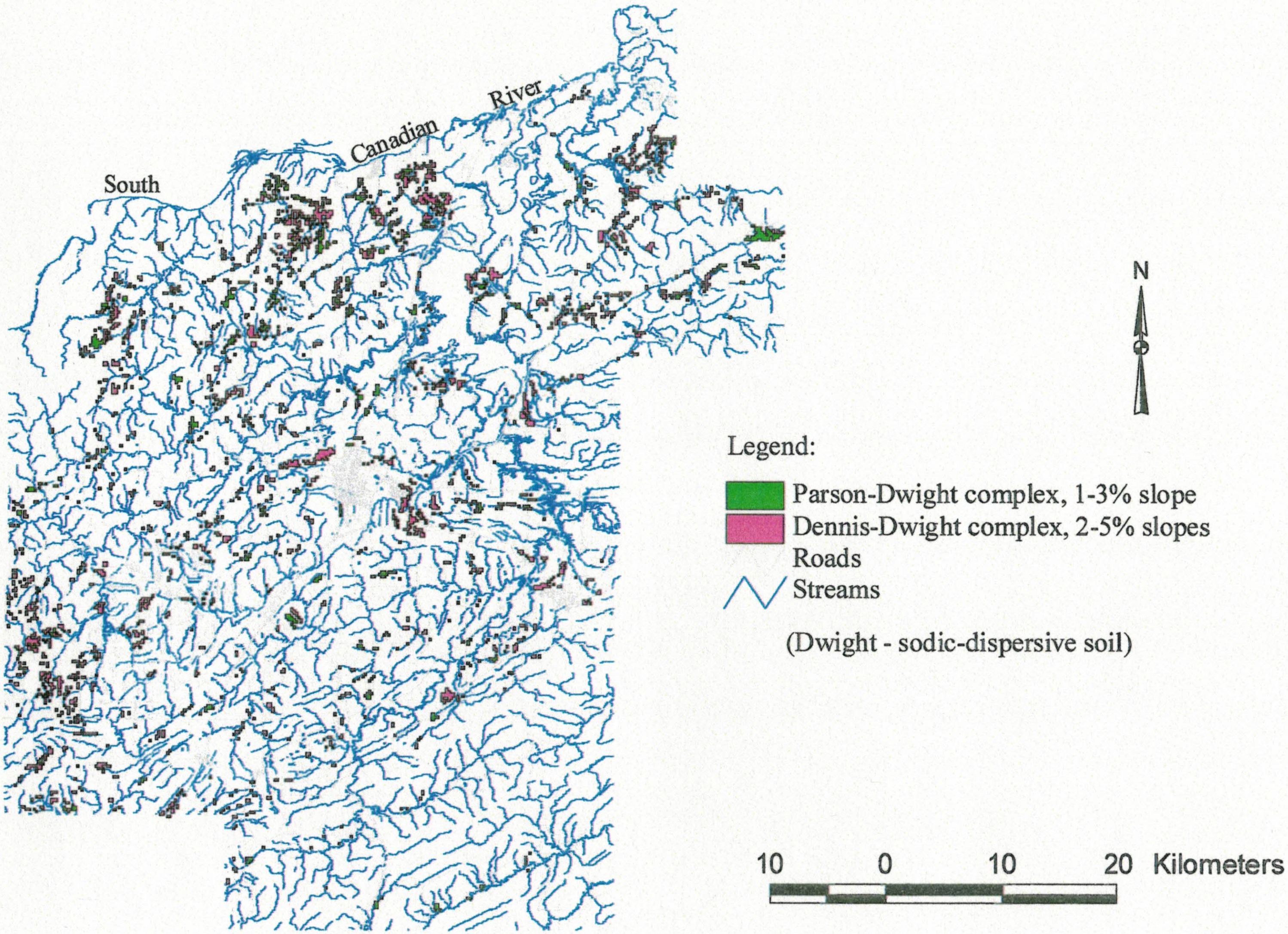


Figure 18. Sodic soils of Pittsburg County, Oklahoma, as identified by county soil survey map (USDA/NRCS).

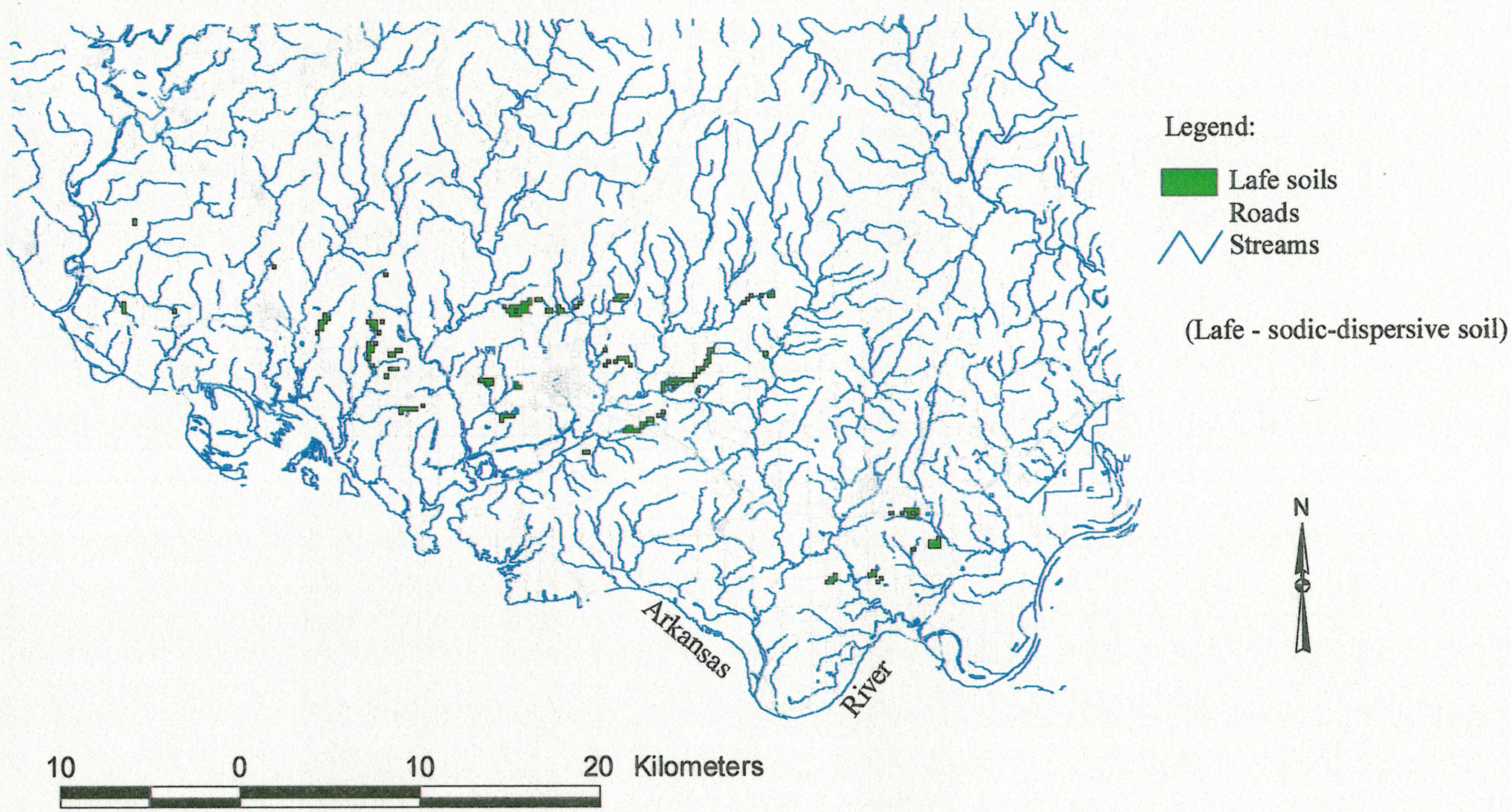


Figure 19. Sodic soils of Sequoyah County, Oklahoma, as identified by digitized county soil survey map (USDA/NRCS).

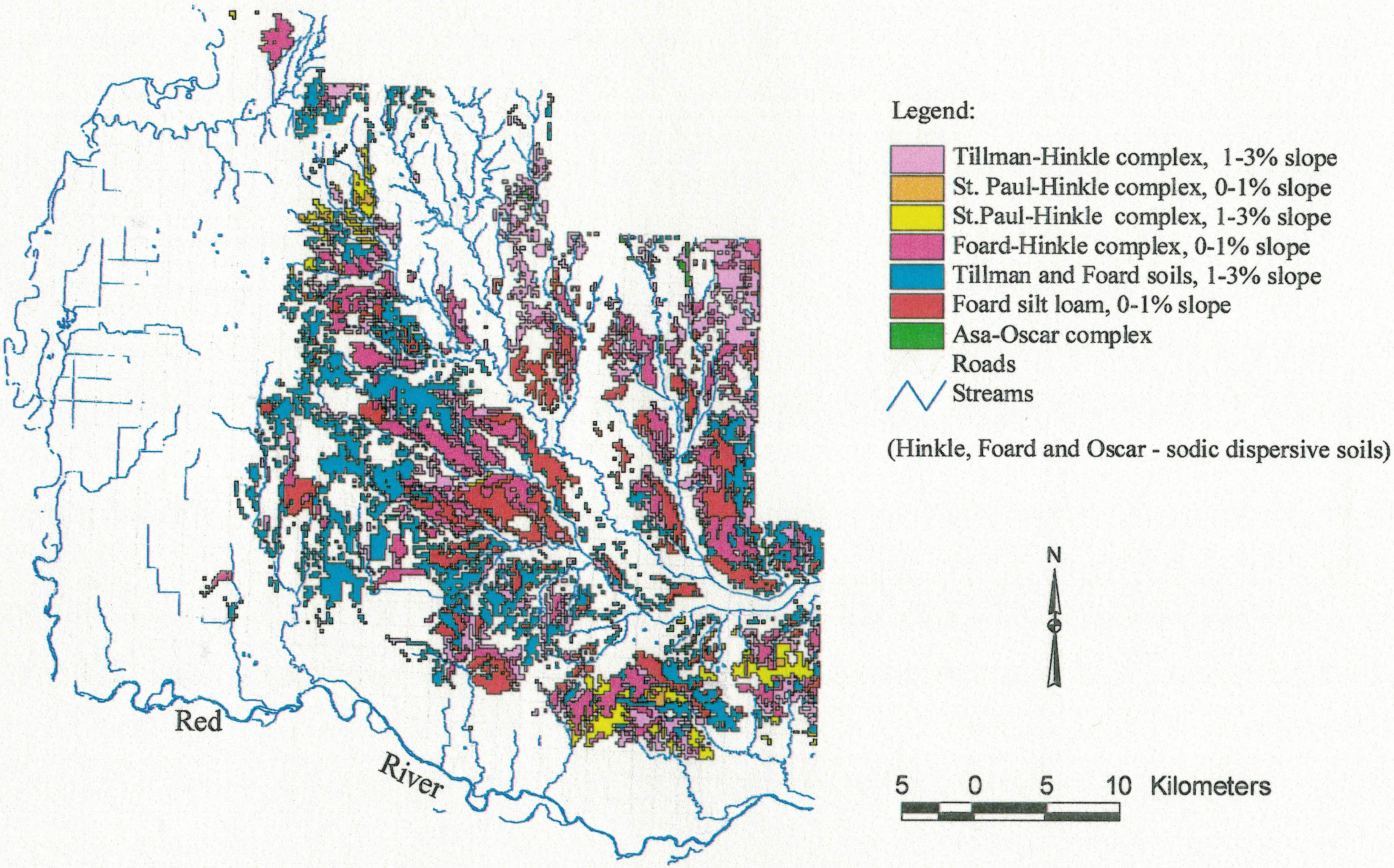


Figure 20. Sodic soils of Tillman County, Oklahoma, as identified by digitized county soil survey map (USDA/NRCS).

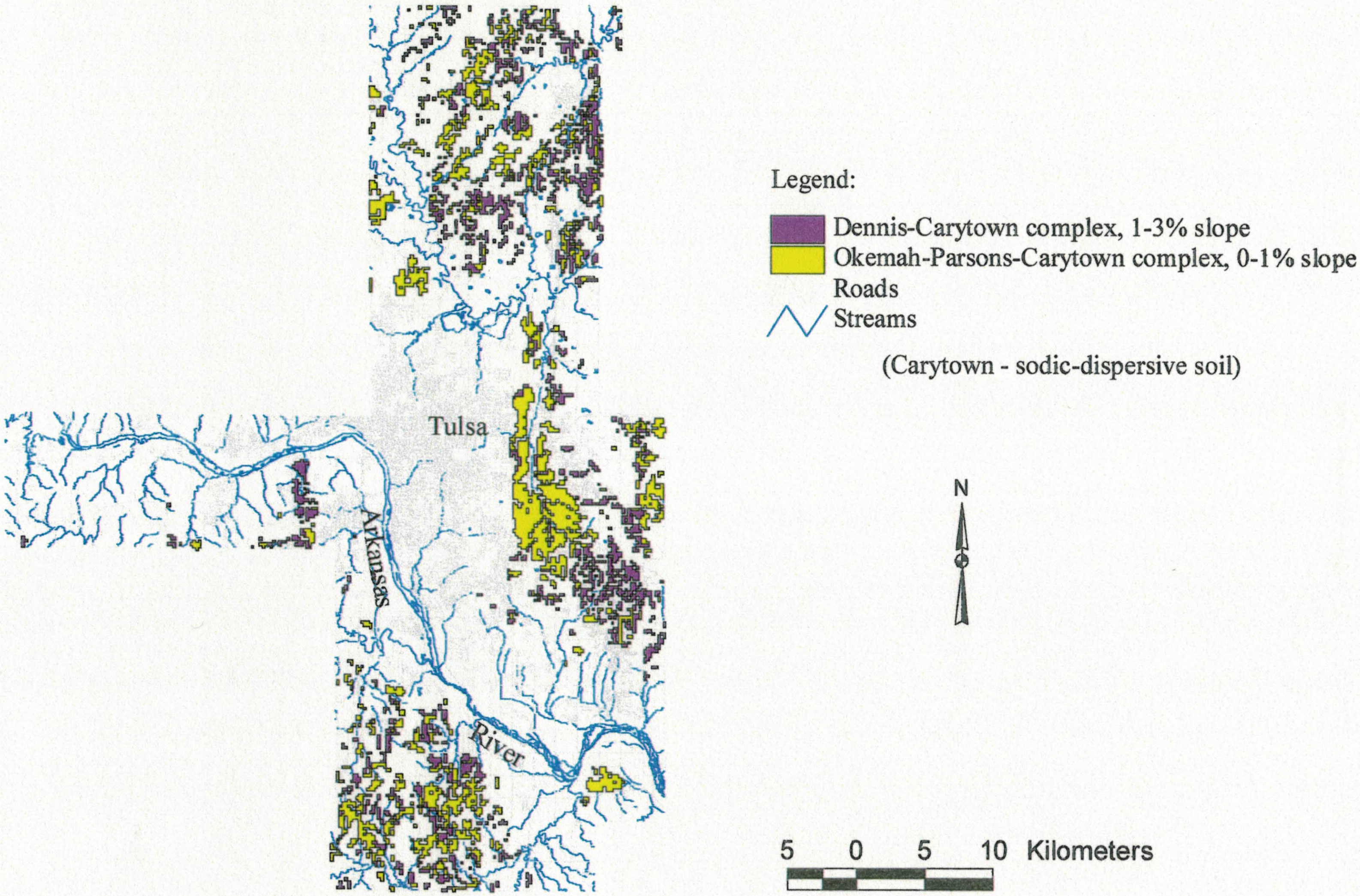


Figure 21. Sodic soils of Tulsa County, Oklahoma, as identified by digitized county soil survey map (USDA/NRCS).

within this report are formatted for 21.5 x 28 cm pages, but can be viewed at larger scales or by particular regions or districts.

Soil Mapping Units Containing Sodic Soils

Soil Associations and Complexes

Soil mapping units are designed for land use and management. Soil mapping units are not pure areas of one soil series (type). Soil mapping units are aggregates of soil series, which occur together on the same landform. Soil mapping units contain several if not many different soil series (Soil Survey Staff, 1993). Some sodic soil areas shown on Figures 3 through 21 contain non-sodic soils. If one soil series predominates a mapping unit (more than 75%) the unit is called a consociation (Soil Survey Staff, 1993), i.e. Wing silt loam, 0-2% slope (Le Flore Co.). Soil mapping units containing more than one soil series are referred to as soil complexes (or associations for scales smaller than 1:50,000), i.e. Zaneis-Wing complex 0-3% slope in Jefferson Co. The name of the complex is represented by the two most abundant soil series within that complex. The name of the dominant (by area) soil is presented first in the name of the complex. Some mapping units consist of two sodic soils, i.e. Doolin-Pawhuska complex 0-3% slope (Cleveland Co.). In this case one of the sodic soils may occupy more than 55% of the unit. The distribution of sodic soils in soil mapping units has not been determined. In complexes, soils are often so intermingled that they can not be separated at the scale selected for mapping (individual areas of each soil are 2 to 8 hectares). However, the majority of sodic soils occupy swales and depressions of round or oval shape and comprise from 10 to 40% of the mapping unit area, which ranges in size from 3 to 81 hectares or larger.

Use of Slickspot or Gumbo Spot Symbol

Sodic soils occurring in soil mapping units are often of small size (0.1 to 0.8 hectares). In several USDA-NRCS county soil surveys a symbol "ø"(designated as slickspot or gumbo spot) identifies the approximate location of small sodic soil areas within the soil mapping units. The word slickspot replaces the name of a sodic soil in the name of the soil mapping unit in several counties where slickspot and gumbo spot symbols are used, i.e. Zaneis-slickspot complex, 0-1 % slope (Table 2). The specific type of sodic soil series is also not specified within a slickspot. Slickspots symbols are not included in originally digitized database, therefore they are not presented in Figures 3 through 21. Maps with identified slickspots locations are only found in published county soil surveys (USDA/NRCS). Areas containing slickspots are valuable in determining sodic soils distribution and should be included in digitized database.

DISPERSION OF SODIC SOILS

Introduction

Measurements of sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) separated soils affected by sodium from other soils. The classification system in use at present and based on research done around 1954 defines a sodic soil as having a measured ESP and SAR value of 15 and 12, respectively. Results from this study, regarding measured amounts of dispersion, indicate a need for an improved classification system for soils of Oklahoma.

Measurement of SAR is less expensive and time-consuming than measurement of ESP and a direct correlation exists between ESP and SAR for soils used in this study (Figure 22). Measurement of SAR is a useable laboratory test for identifying soils in Oklahoma affected by sodium. Although the correlation of SAR and dispersion for soils in this study is not strong (Figure 23), and an increase in the amount of sodium as measured by the SAR value results in an increase in dispersion (determined from a double hydrometer test). Defining more appropriate diagnostic SAR values for identification of sodium-affected (sodic) soils in Oklahoma requires assessment of other soil properties including dispersion, electrical conductivity (EC), pH, special features of the soil (presence of gypsum, carbonates), and ionic composition of the soil pore water (amounts of sodium, chloride, sulfate, calcium, and magnesium in a saturated paste extract).

Diagnostic SAR Value for Oklahoma Soils

The EC is an indirect measure of the amount of salt in a solution. Repulsion between soil particles associated with abundant sodium in pore water and on soil exchange sites decreases when an abundant supply of chloride and sulfate ions are also present. The initial step toward identifying better diagnostic SAR values for soils of Oklahoma is separation of soils based on

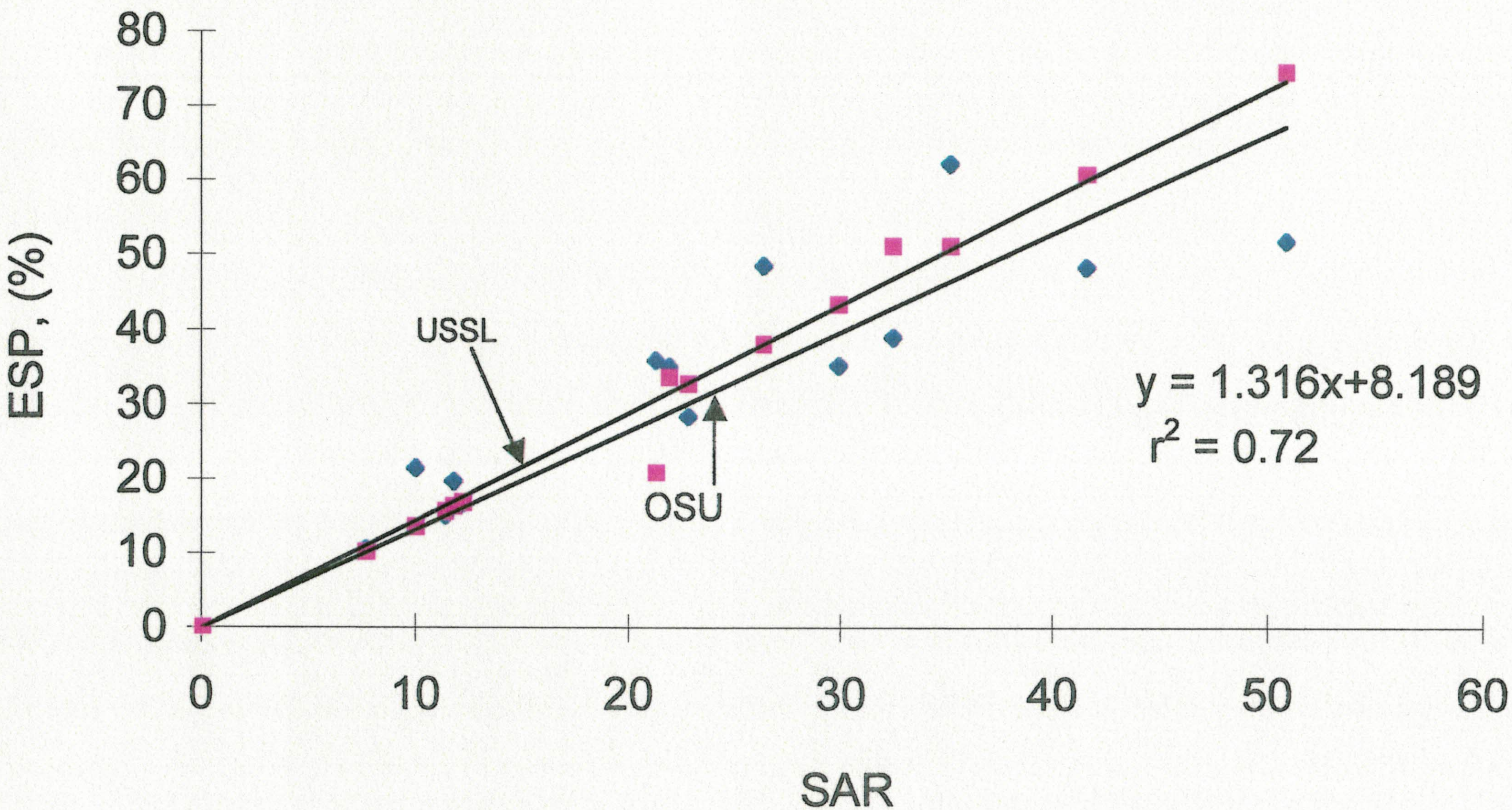


Figure 22. Linear relationship of ESP and SAR for: 1) soils of this study (OSU) and 2) established by the U. S. Salinity Laboratory (USSL) for predicting ESP values from SAR values.

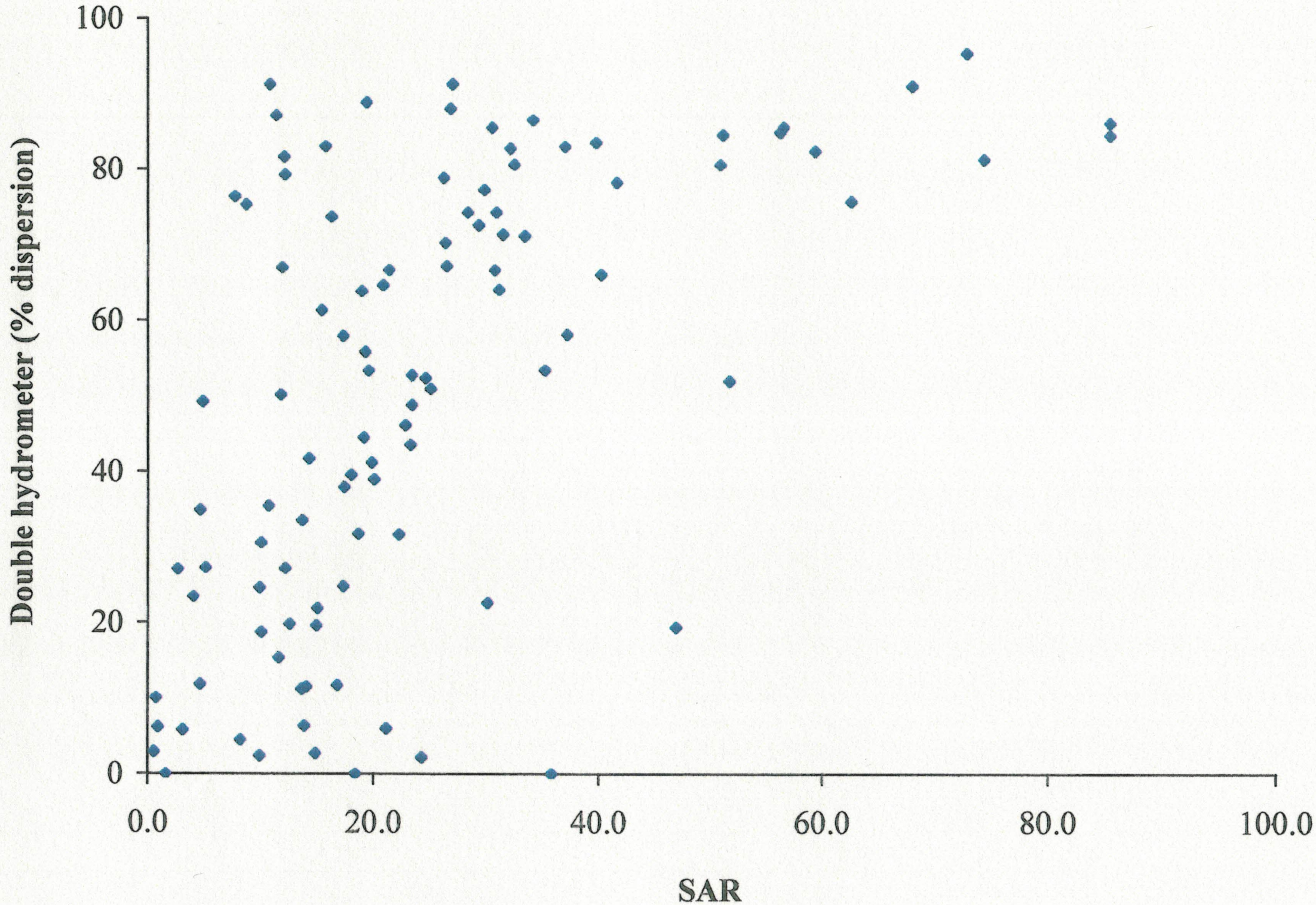


Figure 23. Distribution of SAR versus double hydrometer test values for soil horizons sampled for the study.
Note: Sample no. 23 excluded because of unequal cation to anion balance.

EC values. Results of this study indicate 3 critical EC ranges for soils in Oklahoma in regards to soil dispersion. These ranges are EC less than 1 (low salinity), EC equal to 1.0 to 8.6 (moderate salinity), and EC greater than 8.6 decisiemen per meter (ds/m) (high salinity). Soils in the low salinity range do not have enough chloride and sulfate ions in the soil solution to negate any of the sodium ion effect, soils in the moderate salinity have sufficient chloride and sulfate ions in pore water to inhibit the sodium ion effect, and in soils of the high salinity range sodium and salts contribute to create a level of dispersion that is essentially untreatable. Division of soils used in this study on the basis of EC results in linear relationships of SAR and dispersion for soils in the low (EC less than 1 ds/m) and moderate salinity (EC equal to 1-8.6 ds/m) groups (Figures 24 and 25).

Derivations of critical SAR values for soils in the low and moderate salinity groups are from regression equations for SAR versus dispersion (double hydrometer) relationships (Figures 24 and 25). A value of 30 % dispersion represents the threshold between dispersive and non-dispersive soils based on previous research. Critical SAR values for soils in Oklahoma based on the results of this study were determined by setting the dispersion equal to 30 in the regression equations in Figures 24 and 25 and calculating the SAR values; 4.5 for soils of low salinity and 7.9 for soils with moderate salinity.

Soil Factors Affecting SAR/Dispersion Relationships

The strength of the linear relationships from the regression analyses of the SAR versus dispersion for the soils of low and moderate salinity improved by omitting data for some of soils sampled for the study. Measurements of dispersion (double hydrometer) are available only for soil horizons with master horizon designations of B. Sampling of soils for this study did not include taking samples of A (usually surface), C (parent material or weathered rock), or R

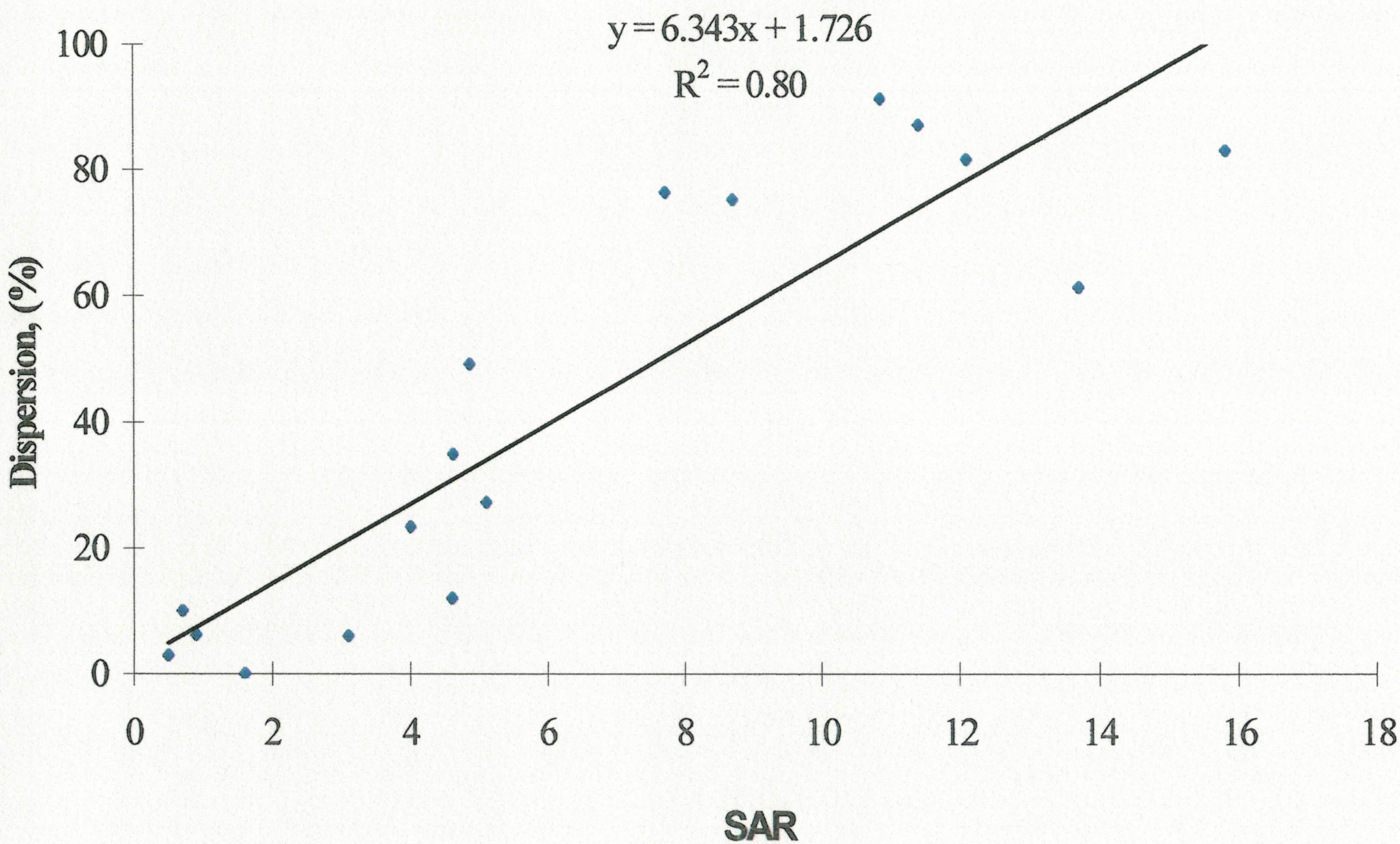


Figure 24. Linear relationship of SAR and double hydrometer test values for sample soils of low salinity (EC<1.0 ds/m).

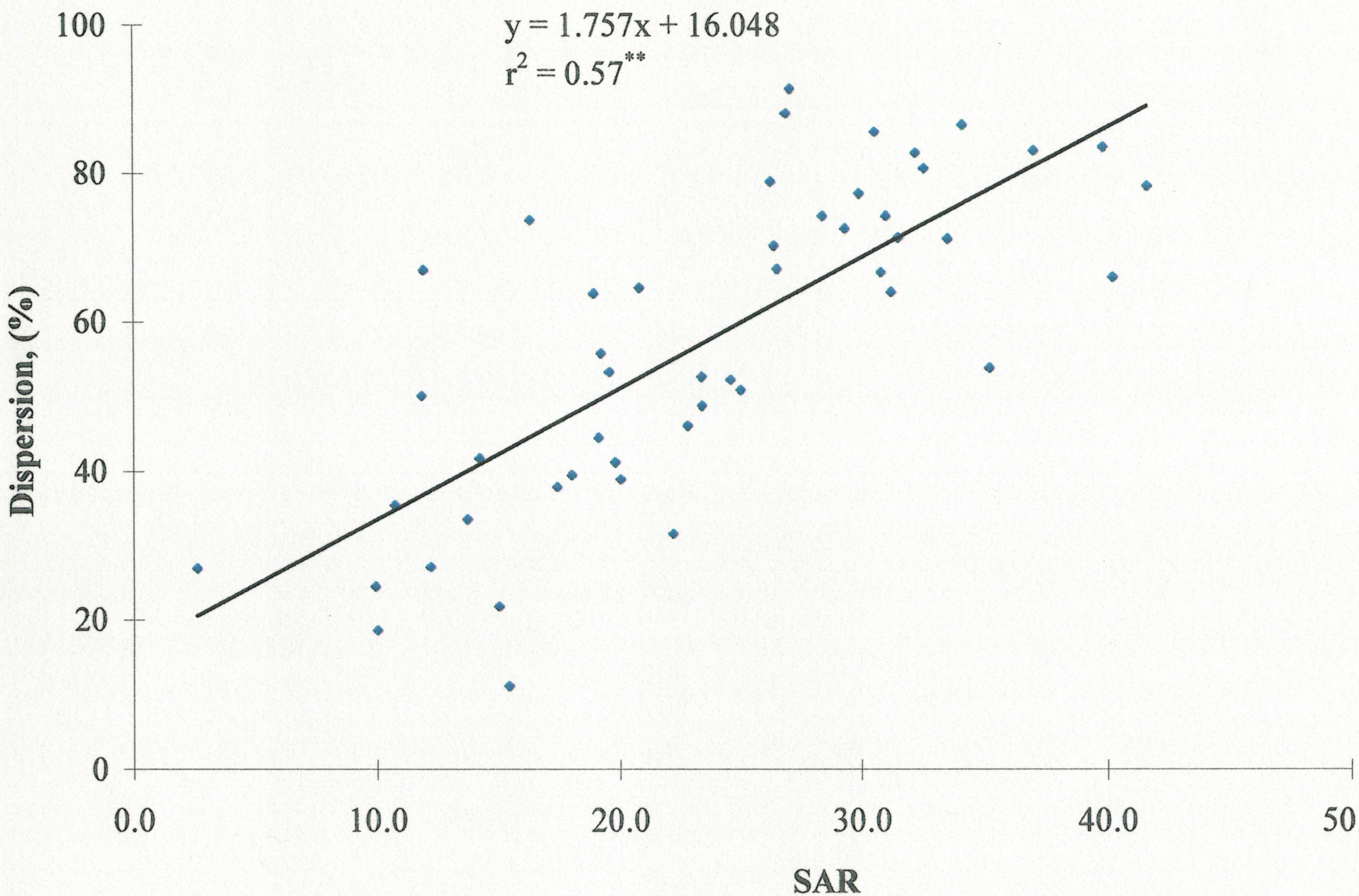


Figure 25. Linear relationship of SAR and double hydrometer test values for sampled soils of moderate salinity (EC= 1.0-8.6 ds/m)

(bedrock) for tests of dispersion so there is no data regarding dispersion for A, C, or R horizons to include in the regressions. Regression analyses did not group the soils of high salinity in this study. A common effect of high salinity occurs in the Btk1 horizon of the Drummond (Canadian Co.) profile (Site 10, Part II page 123). The EC value of the horizon is 10, SAR is 85, and the dispersion is 86%. More than 90% of the cations in solution are monovalent sodium and the presence of other ions does not affect the repulsion of soil particles caused by the sodium. A similar situation occurs in the Btkn3 horizon of the Wing (Jefferson Co.) profile (Site 18, Part II, page 205) (EC equal to 10, SAR equal to 57, and dispersion equal to 86%).

Unique properties of some soils of moderate salinity resulted in exclusion of these soils from the regression analyses for SAR versus dispersion relationships. The amount of dispersion is large in several soils of moderate salinity that have large SAR values. In these soils, as in several of the soils of high salinity, cation content of the soil pore water is nearly all sodium and in the absence of some soil factor to negate the repulsion of soils particles caused by the sodium, the amount of dispersion is large. Soil horizons from the Drummond (Canadian Co.), Healdton (Carter Co.), Wing (Jefferson Co.), Oscar (Jefferson Co.), and Oscar (Tillman Co.) sampling locations are unique and are excluded from the regression analyses. Another soil feature responsible for exclusion of soils of this study from the SAR versus dispersion regression analyses is the presence of gypsum in the soil. The subscript y in a horizon name indicates field identified presence of gypsum and gypsum is identified in several horizons sampled for this study. Dissolution of gypsum adds calcium to the soil solution and increases the amount of divalent calcium in the pore water causing some of the sodium to be removed from the soil exchange sites resulting in a decrease in the amount of dispersion. The amount of dispersion is considerably decreased if enough gypsum is present. Gypsum influences the amount of dispersion in the soil at the Oscar (Tillman Co.) sampling location. The Btnky1 and Btnky2 horizons (Oscar; Site 21, Part II, page 229) in the profile contain gypsum, have SAR values of around 50 and dispersion is only 52 and 19 %, respectively. The horizons directly underneath the Btnky1 and Btnky2, the Btkn3 and Btkn4 horizons do not contain gypsum, have SAR values of around 70 and the dispersion is greater than 90% in these soils. The presence of gypsum also limited dispersion in soils from the Lafe (Sequoyah Co.) (Site 6), Carytown (Muskogee Co.) (Site 7), Doolin (Cleveland Co.) (Site 9), Drummond (Grant Co.) (Site 12), Doolin (Payne Co.) (Site 14), Seminole (Payne Co.) (Site 16), and Foard (Comanche Co.) (Site 20) sampling locations. Presence of gypsum does not always indicate suppressed dispersion as indicated by results from soils at the Carytown (Tulsa Co.) (Site 15) and Oscar (Jefferson Co.) (Site 19) sampling locations where gypsum is present in the soil but the amount of dispersion is still large. A combination of gypsum and other soluble salts in the soil also inhibits dispersion as observed in soils from the Carytown (Muskogee Co.) (Site 7) and Foard (Comanche Co.) (Site 20) sampling locations where gypsum is present, SAR values range from 10 to 20, EC values range from 4 to 8, and the amount of dispersion is small. A large amount of bicarbonate in the pore water of soils from the Dwight (Okmulgee Co.) (Site 8) is responsible for reducing the amount of dispersion. The BCk horizon of the Dwight (Okmulgee Co.) (Site 8, Part II, page 106) profile has an EC value of 0.8, an SAR value of 19, but the amount of dispersion is only 32%.

Dispersion and Clay Mineralogy

The relationships of dispersion and clay mineralogy for soils of the study are complex and interactions of dispersion and other physical and chemical properties (i.e., the presence of gypsum, the amount of sodium in the pore water, EC) of the soils also influence the amount of dispersion in the soils. Analyses of clay mineralogy for 30 horizons included in the study indicate much variation in the types and relative amounts of clay minerals in the soils (Table 8). There are 3 levels of dispersion in the 30 soils analyzed for clay mineralogy; 9 of the soils have no dispersion (less than 30% dispersion as measured by the double hydrometer method), 6 soils have moderate amounts of dispersion (approximately 50% measured dispersion), and 21 soils have strong dispersion (greater than 65% measured dispersion) (Table 8).

Distinguishing characteristics regarding clay mineralogy for the group of soils having no dispersion include 1) mixtures composed primarily of interstratified illite-smectite minerals with vermiculite or smectite (2-27% dispersion), 2) mixtures composed primarily of kaolinite and vermiculite with either of the minerals 2 to 4 times more than the other (0 to 20% dispersion), 3) mixtures composed primarily of equal amounts of vermiculite and kaolinite (12 and 22% dispersion), and 4) less than 10% illite in all the samples. Distinguishing characteristics of soils affected by moderate dispersion include 1) mixtures composed primarily of interstratified illite-smectite or smectite with illite, and kaolinite (46-53% dispersion) and 2) mixtures of equal amounts of kaolinite and vermiculite with 10% or more illite (53 and 58% dispersion). Characteristics of the clay mineralogy of the group of soils affected by strong dispersion include 1) the largest number of samples (9) in the group, mixtures of interstratified illite-smectite or smectite and little or no vermiculite (64 to 87% dispersion), 2)mixtures dominated by vermiculite (60 to 77%) with 16% or less kaolinite (78 to 86% dispersion), 3) mixtures of kaolinite and vermiculite with the kaolinite being twice as much as the vermiculite and less than 5% smectite or interstratified illite-smectite (80% dispersion), 4) mixtures of illite and interstratified illite-smectite with illite being twice the amount of illite-smectite and less than 10% kaolinite (70% dispersion), and 5) mixtures of nearly equal amounts of interstratified illite-smectite and

Table 8. Relationships of Dispersion and Clay Mineralogy for Soils of this Study

					Identified Clay Minerals					
				Dispersion	Mixed*	Smectite	Vermiculite	Illite	Kaolinite	Quartz
Sample No.	ODOT No.	Site	Horizon	%	Relative %*					
<u>No Dispersion</u>										
21	1	Wister (LeFlore)	Bt1	6	3	0	72	6	18	1
22	2	Wister (LeFlore)	Bt2	12	0	3	46	9	40	2
23	3	Wister (LeFlore)	Bt3	22	0	4	43	9	41	2
28	16	Pawhuska (McClain)	Bn1	27	73	0	4	8	5	10
34	20	Lafe (Sequoyah)	Btn1	20	0	11	16	8	62	3
35	21	Lafe (Sequoyah)	Bty2	0	0	0	60	4	33	3
41	24	Carytown (Muskogee)	Btn1	19	70	0	12	5	13	0
85	55	Doolin (Payne)	Btkn3	3	74	0	14	4	7	1
142	93	Hinkle (Kiowa)	Btnky2	2	7	85	0	4	3	1
<u>Moderate Dispersion</u>										
7	15	Bosville (Choctaw)	BC	50	50	0	0	19	27	4
15	4	Wing (LeFlore)	Bt1	53	0	0	43	10	44	3
36	22	Lafe (Sequoyah)	Btky3	58	0	14	30	16	38	2
37	23	Lafe (Sequoyah)	BCk	53	39	0	0	13	47	1
48	30	Dwight (Okmulgee)	Btk2	46	72	0	4	6	15	3
141	92	Hinkle (Kiowa)	Btkn1	51	0	88	0	6	3	3
<u>Strong Dispersion</u>										
6	14	Bosville (Choctaw)	Btn4	76	60	0	0	16	20	4
11	9	Dwight (Pittsburg)	Bt3	87	82	0	0	5	10	3
16	5	Wing (LeFlore)	Bty2	80	0	3	33	6	54	3
17	6	Wing (LeFlore)	2Btk3	86	0	1	77	5	16	1
18	6A	Wing (LeFlore)	2BCk	79	0	1	76	8	14	1
64	43	Dwight (Osage)	Btn2	74	86	0	1	4	6	3

*Randomly or regularly interstratified illite-smectite minerals; percentages based on areas of diagnostic x-ray peaks

Table 8. Relationships of Dispersion and Clay Mineralogy for Soils of this Study (cont.)

Sample No.					Identified Clay Minerals					
Strong Dispersion				Dispersion	Mixed*	Smectite	Vermiculite	Illite	Kaolinite	Quartz
(cont.)	ODOT No.	Site	Horizon	%	Relative %*					
65	44	Dwight (Osage)	Bt3	74	82	0	0	9	6	3
71	45	Drummond (Grant)	A1, b	70	31	0	1	56	6	6
86	56	Doolin (Payne)	Btnyq4	67	36	0	3	15	41	5
94	62	Carytown (Tulsa)	Btnk5	78	1	0	60	27	3	7
122	79	Oscar (Jefferson)	Btn3	81	56	2	0	18	21	5
143	94	Hinkle (Kiowa)	Btkn3	72	87	0	0	7	4	2
144	95	Hinkle (Kiowa)	Btkn4	64	90	0	0	4	4	2
145	96	Hinkle (Kiowa)	Btkn5	67	0	88	0	6	4	2
146	97	Hinkle (Kiowa)	BCk	77	63	0	0	28	6	3

*Randomly or regularly interstratified illite-smectite minerals; percentages based on areas of diagnostic x-ray peaks kaolinite with the remainder as illite (67% dispersion). Results indicate the mineralogy of the clay fraction influences the amount of dispersion affecting a soil.

Comparison of Dispersion Tests

The double hydrometer, pinhole, and crumb tests measure dispersion in soils. Measurements of dispersion by each method are available and reported in Part II of the Final Report. The pinhole and crumb tests identify more of the soils tested as being dispersive compared to the double hydrometer test (Figures 26, 27, 28, and 29). The crumb and pinhole tests are visual qualitative determinations that depend on the experience of the observer. Qualitative tests can be less reliable than similar quantitative tests. The crumb and pinhole tests were not as sensitive for discerning moderate from strong dispersion compared to the double hydrometer test. Pinhole test results coincided more with the double hydrometer data than the crumb tests with fewer of the samples with large amounts of dispersion measured as non-dispersive. The crumb test failed to identify some dispersion soils as non-dispersive. The crumb test failed to identify dispersion when soil EC values were high. The pinhole test did consistently identify dispersive soil as compared to the crumb test. The crumb test is not recommended as a quick field test. Together the pinhole and double hydrometer tests can be used to identify dispersive soils.

Revised Classification System for Saline and Sodic Soils in Oklahoma

Figure 30 is the standard classifications of the soils of this study. Most of the soils are in the saline-sodic, sodic, and non-saline/non-sodic groups. Figure 31 presents the revised classifications of the soils of this study based on the newly defined diagnostic values for EC and SAR. Most of the soils of the study are in the sodic-moderate salinity category. The primary weakness of the standard classification system is the non-recognition of sodic problems for soils

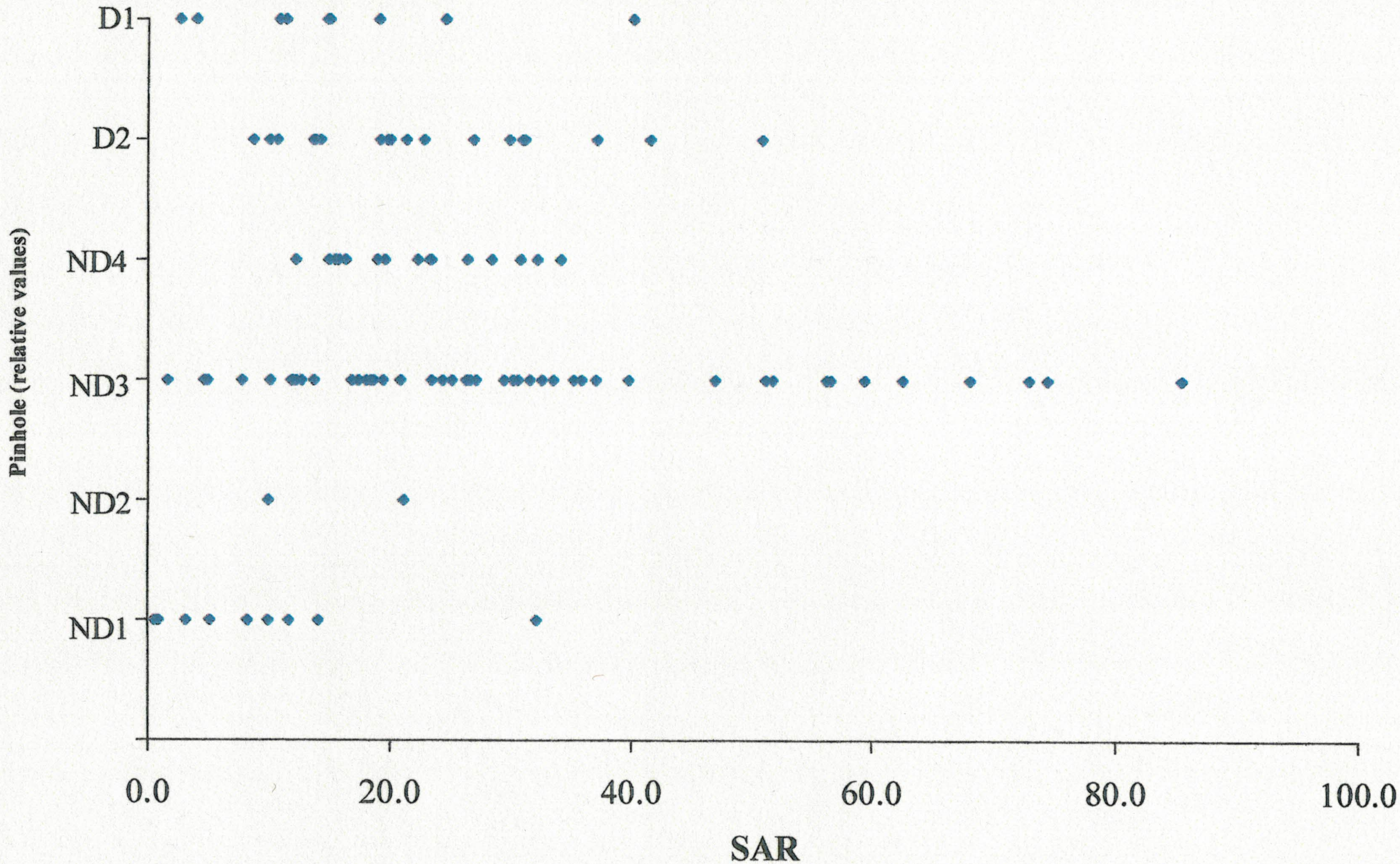


Figure 26. Distribution of SAR versus pinhole test values for soil horizons sampled.
(Note: Sample No. 23 excluded because of unequal cation to anion balance;
Pinhole (relative values): D1 & D2 = dispersive soils, ND3 & ND4 = slightly dispersive soils,
ND1 & ND2 = non-dispersive soils)

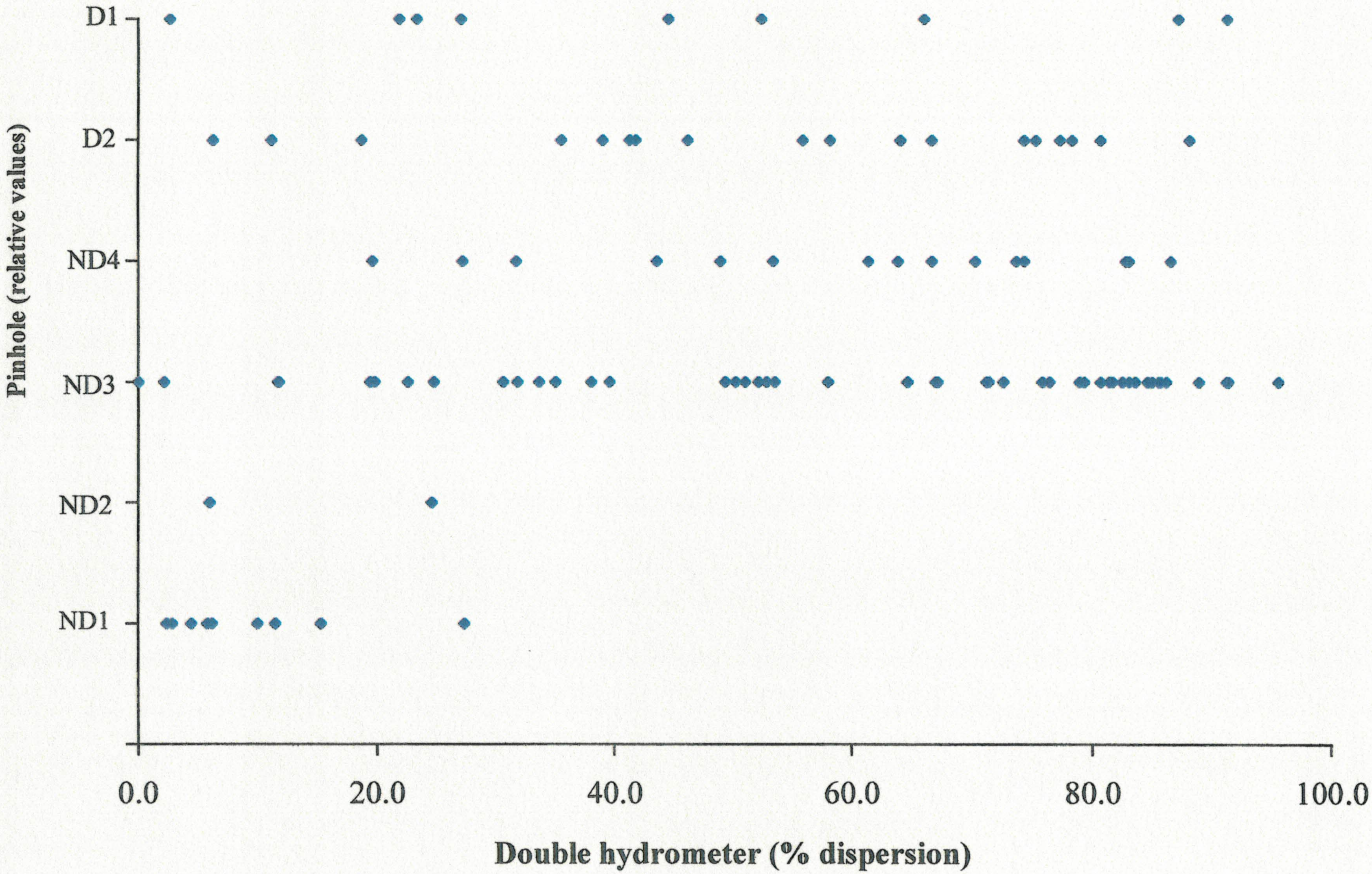


Figure 27. Distribution of double hydrometer test values versus pinhole test values of soil horizons sampled (Note: Sample No. 23 excluded because of unequal cation to anion balance; Pinhole (relative values):D1 & D2 = dispersive soils, ND3 & ND4 = slightly to moderately dispersive, ND1 & ND2 = non-dispersive soils)

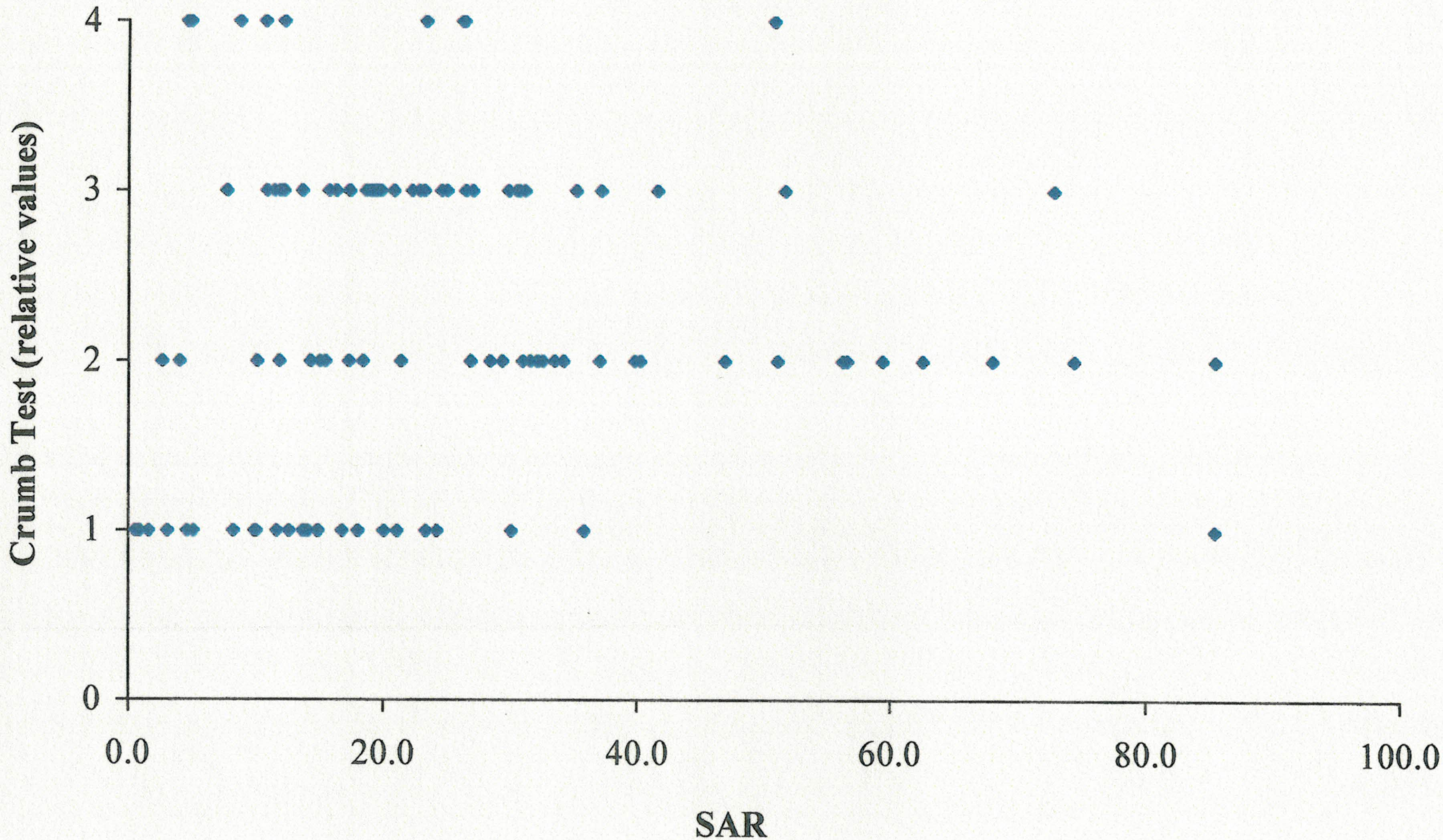


Figure 28. Distribution of SAR versus crumb test values for soil horizons sampled.
(Note: Sample no. 23 excluded because of unequal cation to anion balance;
Crumb Test (relative values): 1-no dispersion, 2-slight dispersion, 3-moderate dispersion, 4-strong dispersion)

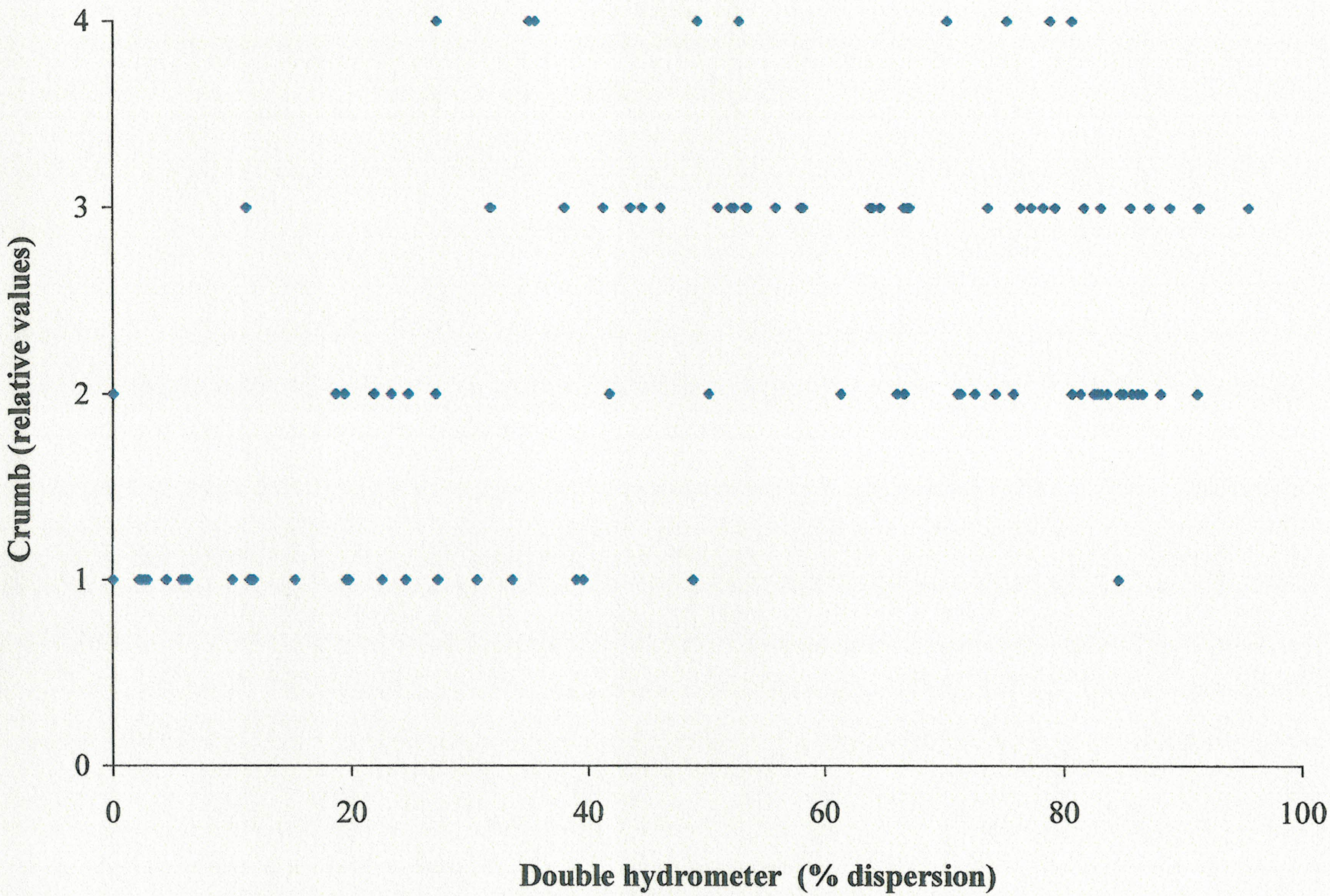


Figure 29. Distribution of double hydrometer test versus crumb test values for soil horizons sampled for this study.
(Note: Sample No. 23 excluded because of unequal cation to anion balance.
Crumb Test (relative values): 1-no dispersion, 2-slight dispersion, 3-moderate dispersion, 4-strong dispersion)

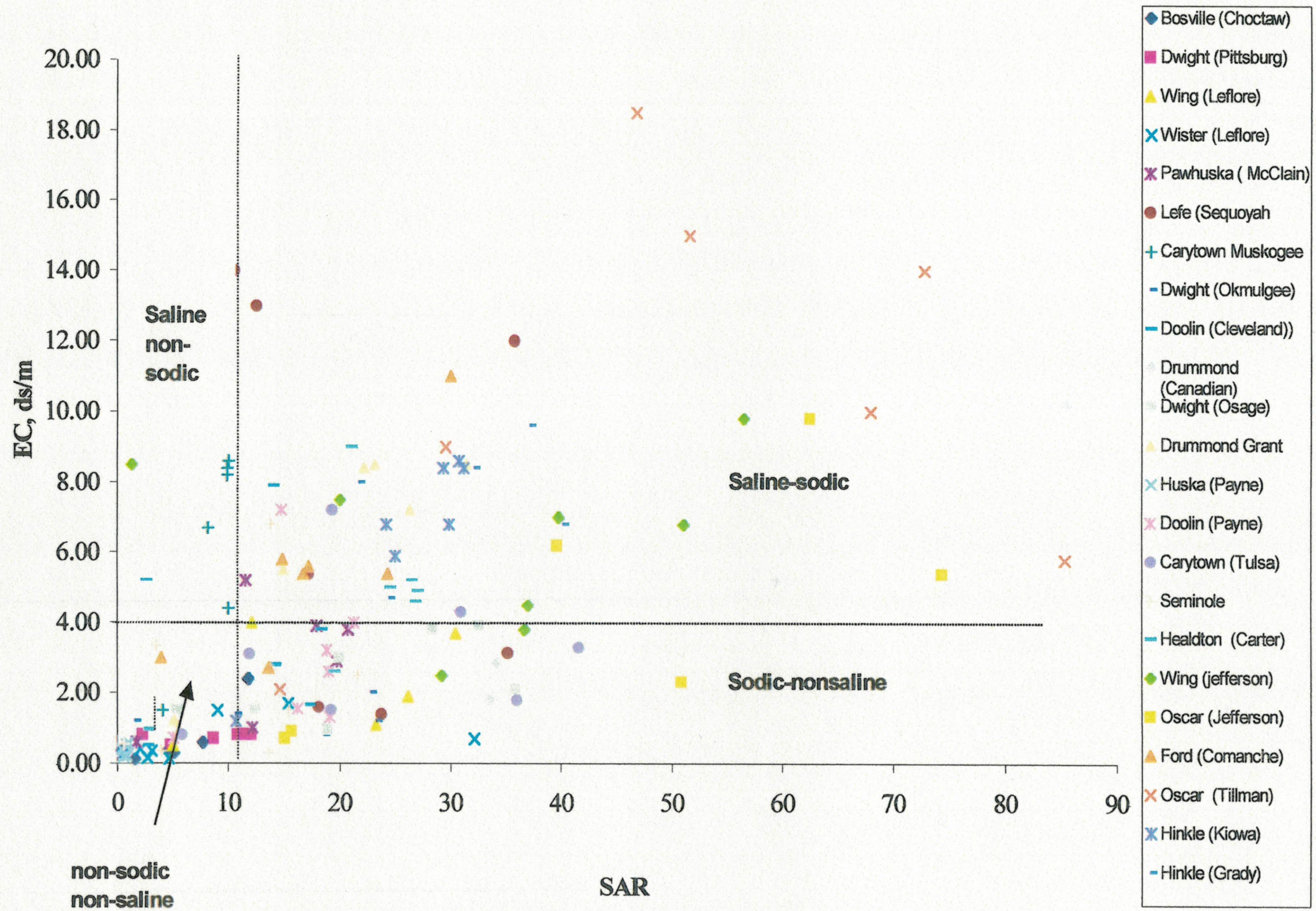


Figure 30. Standard classification of sampled soil horizons (Richards, 1954).

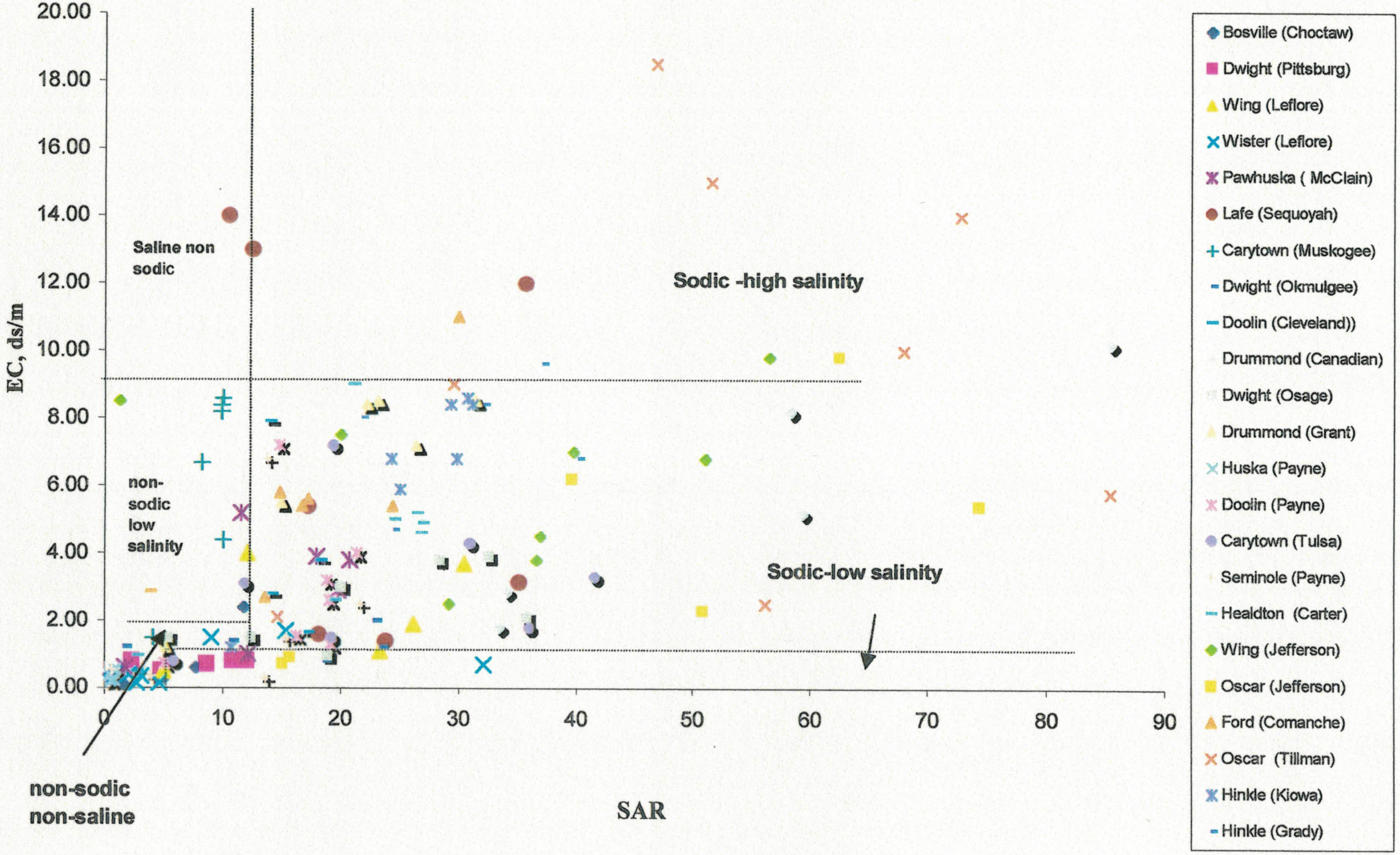


Figure 31. Proposed classification of sampled soil horizons based on newly defined diagnostic SAR values.

with low EC values. Results of this study indicate soils with EC values less than 1 are dispersive when the SAR value of the soil is greater than 4.5. Soils with EC values from 1.0 to 8.6 are dispersive when the SAR value of the soil is greater than 7.9. This new data is important to proper soil use and management of soils in Oklahoma.

RECLAMATION OF SODIC SOILS IN OKLAHOMA USING CHEMICAL AMENDMENTS

Introduction

A part of this study of dispersive soils in Oklahoma involves testing the ability of some chemical amendments to reduce the SAR of selected soils. Reduction of the SAR value below the sodic level for a soil is interpreted as a reduction in the amount of dispersion in a soil and the soil is then considered useable for highway construction. The newly defined diagnostic SAR values from this research project provide a criterion for evaluation of the effectiveness of chemical treatments for reducing the sodicity of soils. ODOT requested testing of cement kiln dust (CKD), fly ash (FL) and hydrated lime (HL) because inexpensive sources of these materials are available to the department and engineers in the department use these materials in the building of roads. ODOT provided a supply of CKD, FL, HL for testing. Evaluation of gypsum (G), calcium chloride (CA), humate (HU) and sulfuric acid (SA) resulted from a review of literature, and research experiences of scientists at Oklahoma State University regarding reduction of sodicity in soils. In this section of the report, identification of amendments is by the acronym in parentheses after the name of the amendment in the first part of this paragraph. The CKD and FL tested are from the Holnam cement factory in Ada, Oklahoma. This plant produces approximately 972 Mg of CKD/day at full production. The source of agricultural grade gypsum (fine powder) is a building supply store in Stillwater, Oklahoma, the Soil Genesis Laboratory at Oklahoma State University (OSU) supplied CA and SA. HU (40% humic acid and 60% filler material) is a product of Heavenly Earth Products, Inc. Revive, Norman Oklahoma. The chemical composition of the amendments used in the treatment of selected sodic soil horizons is given in Table 9. The purpose of the amendment study is to evaluate the ability of

Table 9. Chemical composition of amendments used in the treatment of selected sodic soils.

Element/Compound	CKD†	Fly ash	Gypsum*	Hydrated lime	Humate††	Calcium chloride**
	%					
Silica (SiO_2),	15.14	39.9	-	-	-	-
Aluminum oxide (Al_2O_3)	3.91	16.7	-	-	13.35	-
Iron oxide (Fe_2O_3)	1.97	5.8	-	-	-	0.001
Calcium oxide (CaO)	48.4	24.3	-	-	5.94	-
Ca $(OH)_2$	-	-	-	98	-	-
$CaCl_2$	-	-	-	-	-	74.88
Calcium sulfate	-	-	88.0		-	
Magnesium oxide (MgO)	1.38	4.6	-	0.08	1.49	0.004
Sulfur oxide (SO_3)	4.53	3.3	-		3.0	-
Sodium oxide (Na_2O)	0.19	2.54	-	0.08	60.0	-
Humic acid	-	-	-	-	3.98	-
Others	-	-	-	-	-	-

† CKD = Cement kiln dust

*purchased at Lowe's of Stillwater, building and construction material store

**from Soil Genesis Laboratory

*** CKD, Fly ash, Humate and Hydrated lime supplied by ODOT.

†† Humate = Supplied by Dr. B.J. Carter, Oklahoma State University, Stillwater.

the chemical amendments to decrease the SAR of saturated paste extracts of sodic soils and to provide ODOT guidelines for reclamation of sodic horizons by chemical amendment during road and bridge construction. The selected amendments contain different amounts of divalent cations such as Ca^{2+} and Mg^{2+} for replacing Na^{+} from the exchange sites of sodic soils.

Description of Amending Materials

Hydrated lime ($Ca(OH)_2$) is a white, dry powder obtained by hydrating quicklime (CaO) with water (24.32%). Hydrated lime is a hydroxide that ionizes in water into Ca^{2+} and OH^{-} ions. The solubility of hydrated lime is 0.185 g/100 ml at 0 ^{0}C and decreases as the temperature increases. Incorporation of HL into surface layers of several dams built on Suaw Creek near Lawton, Oklahoma effectively reduced dispersion of the soils (Ryker, 1977). Gypsum ($CaSO_4.2H_2O$) is a commonly used amendment for the reclamation of sodic soils. Gypsum is a white mineral found abundantly in some parts Oklahoma; is soluble in water, and is a direct source of calcium. Gypsum applied to dispersive soils at various rates, reduces surface crusting and soil sealing. Calcium chloride ($CaCl_2 .2H_2O$) is a soluble salt that adds Ca^{2+} rapidly to soil. Reaction of CA in sodic soil is similar to gypsum. Fly ash and CKD are industrial byproducts often landfilled as waste products. Fly ash and CKD are not commonly used for reclamation of sodic soils, but are commonly used by ODOT in cement and concrete products, structural fills, and as base material for roads. Fly ash is a finely divided residue resulting from the combustion of pulverized coal. Sulfuric acid (H_2SO_4) is an oily corrosive liquid. Application of SA to soils containing calcium carbonate, causes formation of calcium sulfate and provides Ca^{2+} to the pore water of a soil. Use of SA as an amendment is not a common practice in Oklahoma. The primary reason for using SA as an amendment in the treatment of sodic soil is to remove excess sodium in the form of sodium sulfate.

The time needed for reclamation of sodic soil depends on the amount of water applied (amount of leaching), the concentration of Ca^{2+} in the amending material and in the soil solution, soil texture and ESP of the soil. Rates of application used in this study are based on results of previous studies and a calculation of the amount of Ca^{2+} present in the amendments (Table 10). Rates of application used in this study are 11.2 Mg/ha, 22.4 Mg/ha, 224 Mg/ha and site specific (based on the amount of Ca^{2+} in the amendments and the amount of amendment required to replace all of the sodium on the cation exchange sites in the soil).

Effects of Treatments on Soils Selected for Amendment

Introduction

Soils selected for treatment in the amendment study are from the Bosville (Choctaw) (Site 1), Wing (Leflore Co.) (Site 3), Pawhuska (McClain Co.) (Site 5), Dwight (Osage Co.) (Site 11), Doolin (Payne Co.) (Site 14) and Hinkle (Kiowa Co.) (Site 22) sampling locations (Table 11), Criteria for selection of soils to be treated included EC (less than 4 ds/m), pH (slightly alkaline to alkaline), and SAR (greater than 7). Selected soils have large amounts of Na^{+} in pore water and high SAR. Clay is the dominant soil texture in the 40-100 cm depth of the soil profiles. A complete set of data for each of the horizons selected for amending is in Part II (database of the final report for this study).

Criteria used to evaluate the ability of treatments to reduce the sodicity/dispersivity of sodic soils are the newly defined or proposed diagnostic SAR values previously discussed in the section of this report concerning dispersion of soils in Oklahoma. Successful treatments reduce the SAR values for soils of low salinity (EC less than 1 ds/m) to less than 4.5 and SAR values for soils of moderate salinity (EC equal to 1.0 to 8.6 ds/m) to less than 7.9.

Table 10. Amounts of amendments used in site specific applications

Sample #	Gypsum	Fly ash	CKD*	Hydrated lime
	----------	----------	Mg/ha ----------	----------
6	1.92	4.36	1.61	1.40
7	3.58	8.12	3.00	2.60
11	3.62	8.21	3.03	2.63
15	6.40	14.50	5.36	4.65
28	4.86	11.00	4.07	3.52
37	11.80	26.75	9.89	8.57
41	5.17	11.72	4.33	3.75
48	8.10	18.36	6.79	5.88
64	1.00	2.26	0.83	0.72
71	10.46	23.69	8.76	7.59
85	7.39	16.75	6.19	5.37
94	12.69	28.75	10.63	9.21
122	8.46	19.18	7.09	6.14
146	7.73	17.54	6.47	5.60

*Cement kiln dust

Table 11. Physical and chemical characteristics of soils selected for amendment

Sample No.	Soil Series	Horizon	Depth[*] (cm)	pH[†]	EC[‡] (ds/m)	SAR[§]	Disp[¶] (%)	Clay[#] (%)	Organic Carbon (%)	$CaCO_3$ (%)	Total Carbon (%)
6	Bosville	Bty4	168	6.7	0.6	7.7	76.4	30.1	0.2	0.0	0.2
7	Bosville	BC	200	7.0	2.4	11.8	50.2	32.5	0.2	0.0	0.2
15	Wing	Bt1	41	6.1	1.1	23.4	52.8	42.0	0.8	0.0	0.8
28	Pawhuska	Bn1	55	8.4	1.0	12.2	27.2	38.4	0.6	0.0	0.6
65	Dwight	Bt3	95	8.4	3.9	32.5	80.7	51.9	0.3	0.2	0.5
86	Doolin	Btnyq4	136	7.6	4.0	21.3	66.7	37.6	0.3	0.0	0.3
146	Hinkle	BCk	200	7.8	6.8	29.9	77.3	22.0	0.1	2.4	2.5

[*] depth to bottom of horizon
[†] pH of a saturated paste extract
[‡] electrical conductivity, decisimens per meter
[§] sodium adsorption ratio
[¶] % dispersion by the double hydrometer method
[#] percent <2 micron diameter particles in soil

Successful reclamation of sodic soil requires leaching before and after application of chemical amendments to remove dissolved sodium salts ($NaHSO_4$ and Na_2SO_4). Results from this study indicate leaching alone can reduce the SAR of a soil by as much as 10% depending on the soil texture. The quantity and quality of water applied influences the efficiency of leaching. Irrigation water from rivers that no longer have sources of calcium salts causes dispersion and crust formation in some soils. In areas where water is not limited, sodic soils are reclaimed with successive applications of water containing divalent cations. Results of this study also indicate the importance of leaching to successfully reclaim sodic soils.

<u>Results of Amending the BC horizon of the Bosville (Choctaw Co.) soil (Site 1, Part II, page 14)</u>

The Bosville (Choctaw Co.) sampling location is in southeast Oklahoma. A bridge approach built in part from the Bosville soil failed because of dispersion of the soil. The BC horizon is sodic-moderately saline and successful treatments must reduce the SAR value of the soil to below 7.9. Amendments tested on this soil include G, HL, FL, CKD, HU, CA, SA. Table 12 summarizes the treatment results for the Bosville soil. Amendments most successful in reducing the SAR of the soil include G, HL, CA, and SA. Figures. 32-38 provide an example of the data found in Part II concerning treatments for the other sites containing soils selected for amending.

<u>Results of Amending the Bt1 horizon of the Wing (Leflore Co.) soil (Site 3, Part II page 42)</u>

The Wing (LeFlore Co.) site is located in the eastern part of Oklahoma. The Bt1 horizon is sodic-moderately saline. Treatments tested include CA and SA in combination with G, HL,

Table 12. Site 1. Amendment Study- Bosville (Choctaw) BC Horizon (Sample No. 7, ODOT No. 15) Treatment Data[&]

Treatments[#]	Initial pH[*] (pre-treatment)	Final pH[*] (post-treatment)	Initial SAR[+]	Final Leaching SAR[+]	Change in SAR[+], %	Effectiveness[++] (Proposed)	Effectiveness[++] (Standard)
Gypsum, 11.2 Mg ha^{-1}, 1st leaching	7.0	7.3	11.8	10.2	13.6	no	yes
Gypsum, 11.2 Mg ha^{-1}, leaching	7.0	6.7	11.8	6.4	45.8	yes	yes
Gypsum, 22.4 Mg ha^{-1}, 1st leaching	7.0	7.2	11.8	10.1	14.4	no	yes
Gypsum, 22.4 Mg ha^{-1}, leaching	7.0	7.2	11.8	6.9	41.5	yes	yes
Gypsum, 224 Mg ha^{-1}, 1st leaching	7.0	7.8	11.8	9.9	16.1	no	yes
Gypsum, 224 Mg ha^{-1}, leaching	7.0	8.4	11.8	3.2	72.9	yes	yes
Hydrated lime, 11.2 Mg ha^{-1}, 1st leaching	7.0	10.5	11.8	21.6	-83.1	no	no
Hydrated lime, 11.2 Mg ha^{-1}, leaching	7.0	11.3	11.8	6.6	44.1	yes	yes
Hydrated lime, 22.4 Mg ha^{-1}, 1st leaching	7.0	11.7	11.8	18.2	-54.2	no	no
Hydrated lime, 22.4 Mg ha^{-1}, leaching	7.0	7.5	11.8	3.4	71.2	yes	yes
Hydrated lime, 224 Mg ha^{-1}, 1st leaching	7.0	12.3	11.8	12.9	-9.3	no	no
Hydrated lime, 224 Mg ha^{-1}, leaching	7.0	12.8	11.8	5.0	57.6	yes	yes
Fly ash, 11.2 Mg ha^{-1}, 1st leaching	7.0	7.8	11.8	12.0	-1.7	no	no
Fly ash, 11.2 Mg ha^{-1}, leaching	7.0	8.4	11.8	9.4	20.3	no	yes
Fly ash, 22.4 Mg ha^{-1}, 1st leaching	7.0	7.9	11.8	15.7	-33.1	no	no
Fly ash, 22.4 Mg ha^{-1}, leaching	7.0	7.4	11.8	6.6	44.1	yes	yes
Fly ash, 224 Mg ha^{-1}, 1st leaching	7.0	10.2	11.8	19.3	-63.6	no	no
Fly ash, 224 Mg ha^{-1}, leaching	7.0	10.4	11.8	9.6	18.8	no	yes
Cement kiln dust, 11.2 Mg ha^{-1}, 1st leaching	7.0	6.9	11.8	13.2	-11.9	no	no
Cement kiln dust, 11.2 Mg ha^{-1}, leaching	7.0	7.5	11.8	9.6	18.6	no	yes
Cement kiln dust, 224 Mg ha^{-1}, 1st leaching	7.0	12.6	11.8	9.8	16.9	no	yes
Cement kiln dust, 224 Mg ha^{-1}, leaching	7.0	12.0	11.8	6.1	48.3	yes	yes
Humate, 11.2 Mg ha^{-1}, 1st leaching	7.0	6.5	11.8	17.0	-44.1	no	no
Humate, 11.2 Mg ha^{-1}, leaching	7.0	7.6	11.8	15.3	-29.7	no	no
Humate, 22.4 Mg ha^{-1}, 1st leaching	7.0	7.5	11.8	16.7	-41.5	no	no
Humate, 22.4 Mg ha^{-1}, leaching	7.0	7.6	11.8	10.0	15.3	no	yes

Table 12. Site 1. Amendment Study- Bosville (Choctaw) BC Horizon (Sample No. 7, ODOT No. 15) Treatment Data (cont.)[&]

Treatments[#]	Initial pH*	Final pH*	Initial SAR[+]	Final Leaching SAR[+]	Change in SAR[+], %	Effectiveness[++] (Proposed)	Effectiveness[++] (Standard)
Calcium chloride, 11.2 Mg ha^{-1}, 1st leaching	7.0	6.8	11.8	7.3	38.1	yes	yes
Calcium chloride, 11.2 Mg ha^{-1}, leaching	7.0	6.6	11.8	3.2	73.0	yes	yes
Sulfuric acid, Gypsum 11.2 Mg ha^{-1},1st leaching	7.0	6.5	11.8	7.7	34.7	yes	yes
Sulfuric acid, Gypsum 11.2 Mg ha^{-1}, leaching	7.0	7.4	11.8	4.9	58.5	yes	yes
Sulfuric acid, Hydrated lime 11.2 Mg ha^{-1}, 1st leaching	7.0	10.4	11.1	11.1	0.0	no	yes
Sulfuric acid, Hydrated lime 11.2 Mg ha^{-1}, leaching	7.0	7.7	11.8	9.6	19.1	no	yes
Sulfuric acid, Cement kiln dust 11.2 Mg ha^{-1}, 1st leaching	7.0	8.0	11.8	8.9	24.6	no	yes
Sulfuric acid, Cement kiln dust 11.2 Mg ha^{-1}, leaching	7.0	7.7	11.8	5.3	55.1	yes	yes
Sulfuric acid, Cement kiln dust 22.4 Mg ha^{-1}, leaching	7.0	7.5	11.8	5.8	50.8	yes	yes
Sulfuric acid, Fly ash 11.2 Mg ha^{-1}, 1st leaching	7.0	6.4	11.8	6.3	46.6	yes	yes
Sulfuric acid, Fly ash 11.2 Mg ha^{-1}, leaching	7.0	7.4	11.8	5.2	55.9	yes	yes
Sulfuric acid, Fly ash 22.4 Mg ha^{-1}, leaching	7.0	8.1	11.8	6.7	43.2	yes	yes
Sulfuric acid, Humate 11.2 Mg ha^{-1},1st leaching	7.0	7.7	11.8	12.2	-3.4	no	no
Sulfuric acid, Humate 11.2 Mg ha^{-1}, leaching	7.0	7.1	11.8	7.9	33.1	yes	yes
Sulfuric acid, Humate 22.4 Mg ha^{-1}, leaching	7.0	7.0	11.8	7.3	38.1	yes	yes
Sulfuric acid (36 meq/100 g soil)[##], 1st leaching	7.0	7.0	11.8	15.9	-34.7	no	no
Sulfuric acid (36 meq/100 g soil)[##], leaching	7.0	6.8	11.8	25.7	-117.8	no	no

[&]Threshold values for % change in SAR: Proposed system- 33.1, Standard system- -27.1; Proposed system threshold SAR=((Initial SAR-the proposed SAR (7.9))/ (Initial SAR)*100;Standard threshold SAR=((Initial SAR-15.0)/(Initial SAR))*100

[#]Leaching included 5 successive saturations/extractions of treated soil

*Pre-treatment pH=pH reading before chemical treatment; *Post-treatment pH=pH reading after chemical treatment;

[+]Initial SAR - Sodium Adsorption Ratio without chemical treatment ;[+] Final SAR - Sodium Adsorption Ratio with chemical treatment; [+] Change in SAR=((Initial SAR - Final SAR)/Initial SAR)*100.

[++] Evaluation based on decrease in SAR in relation to diagnostic value for sodic classification;

[##]All other treatments including sulfuric acid were at a rate of 7 meq/100 g soil sulfuric acid.

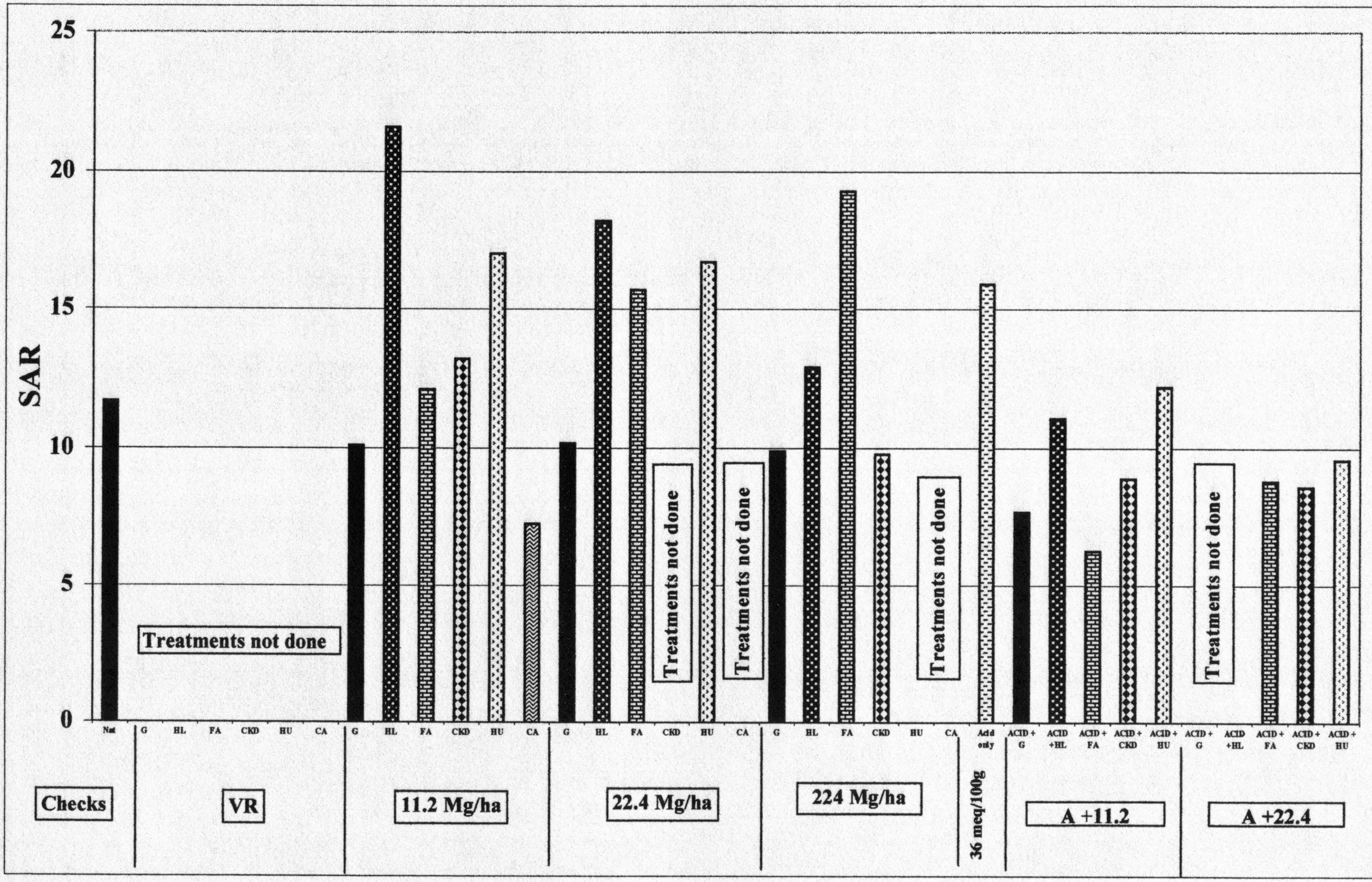


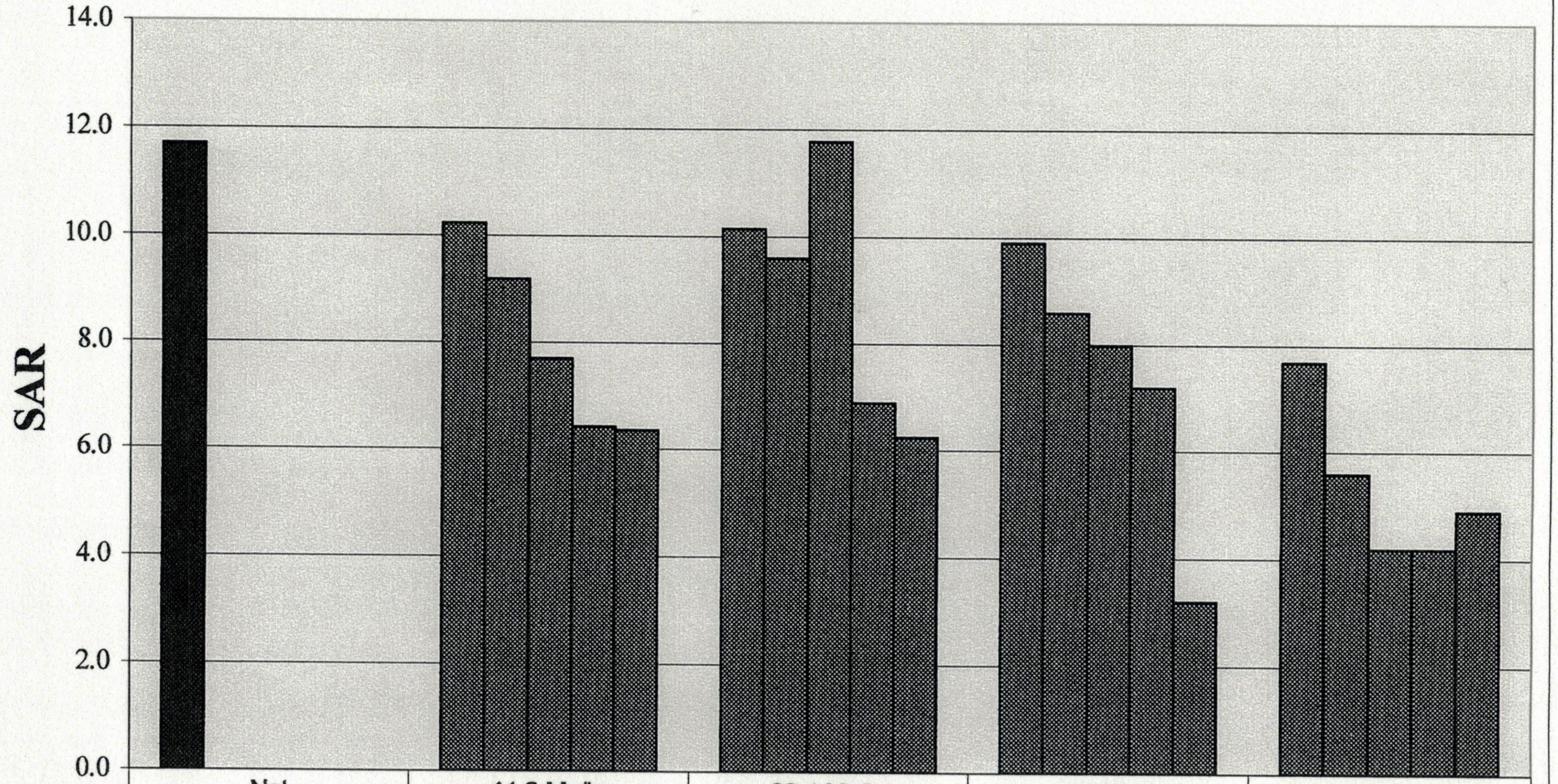
Figure 32. Initial Results of Application of Amendments on Sample No. 7, Site 1, Bosville (Choctaw) (ODOT No. 15)*

(Nat=Unamended, G=Gypsum, FA=Fly ash, CKD=Cement kiln dust, Hu=Humate, CA= Calcium chloride,

Acid+G=Acid and Gypsum, Acid+FA= Acid and Fly ash, Acid+HL=Acid and Hydrated lime, Acid+CKD=Acid and Cement kiln dust, Acid+Hu=Acid and Humate

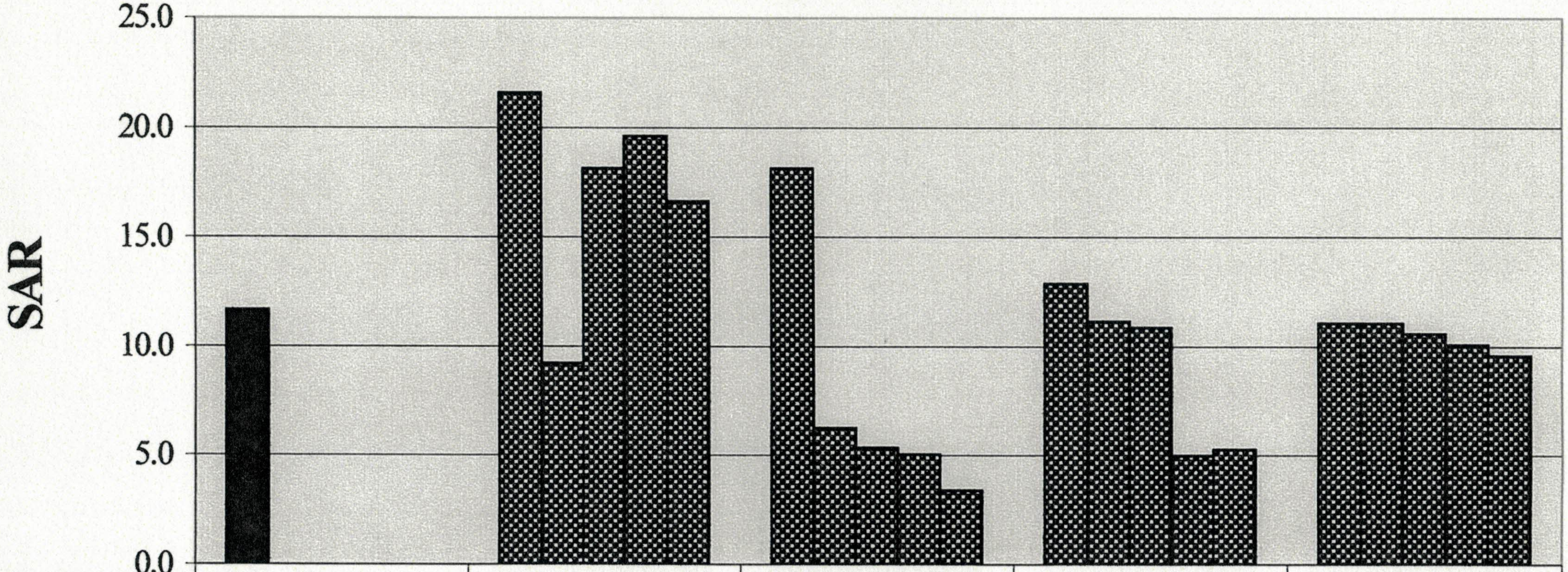
Checks=No treatment, VR=Variable Rates, A+11.2 Mg/ha=Acid and 11.2 Mg/ha amendments, A+22.4 Mg/ha=Acid and 22.4 Mg/ha amendments

*SAR values of the first saturated paste extract taken after addition of amendments)



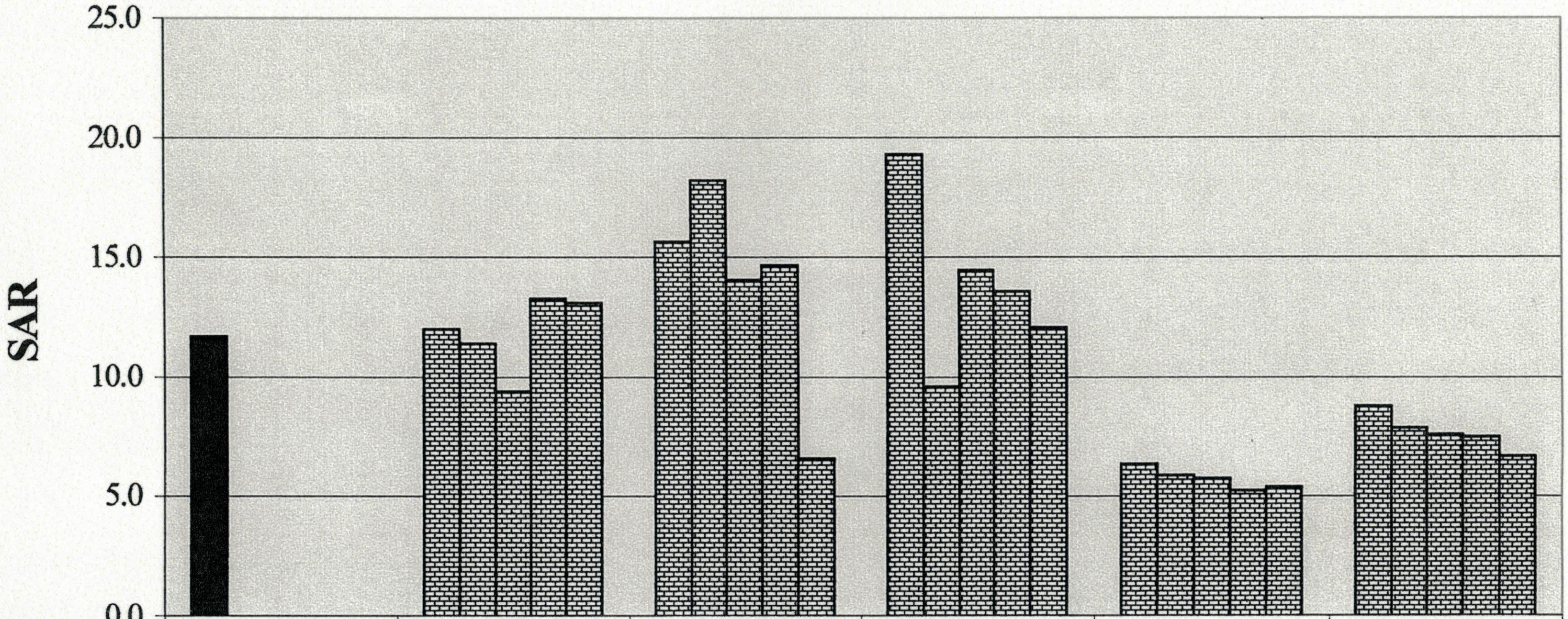
	Nat	11.2 Mg/ha	22.4 Mg/ha	224 Mg/ha	11.2 Mg/ha + acid
Leach 1	11.7	10.2	10.1	9.9	7.7
Leach 2		9.2	9.6	8.6	5.6
Leach 3		7.7	11.8	8.0	4.2
Leach 4		6.4	6.9	7.2	4.2
Leach 5		6.4	6.3	3.2	4.9

Figure 33. Site 1- Bosville (Choctaw Co.)- Effects of Leaching and Gypsum Application on Sample No. 7 (ODOT NO. 15)
Nat= Natural (no amendment applied)



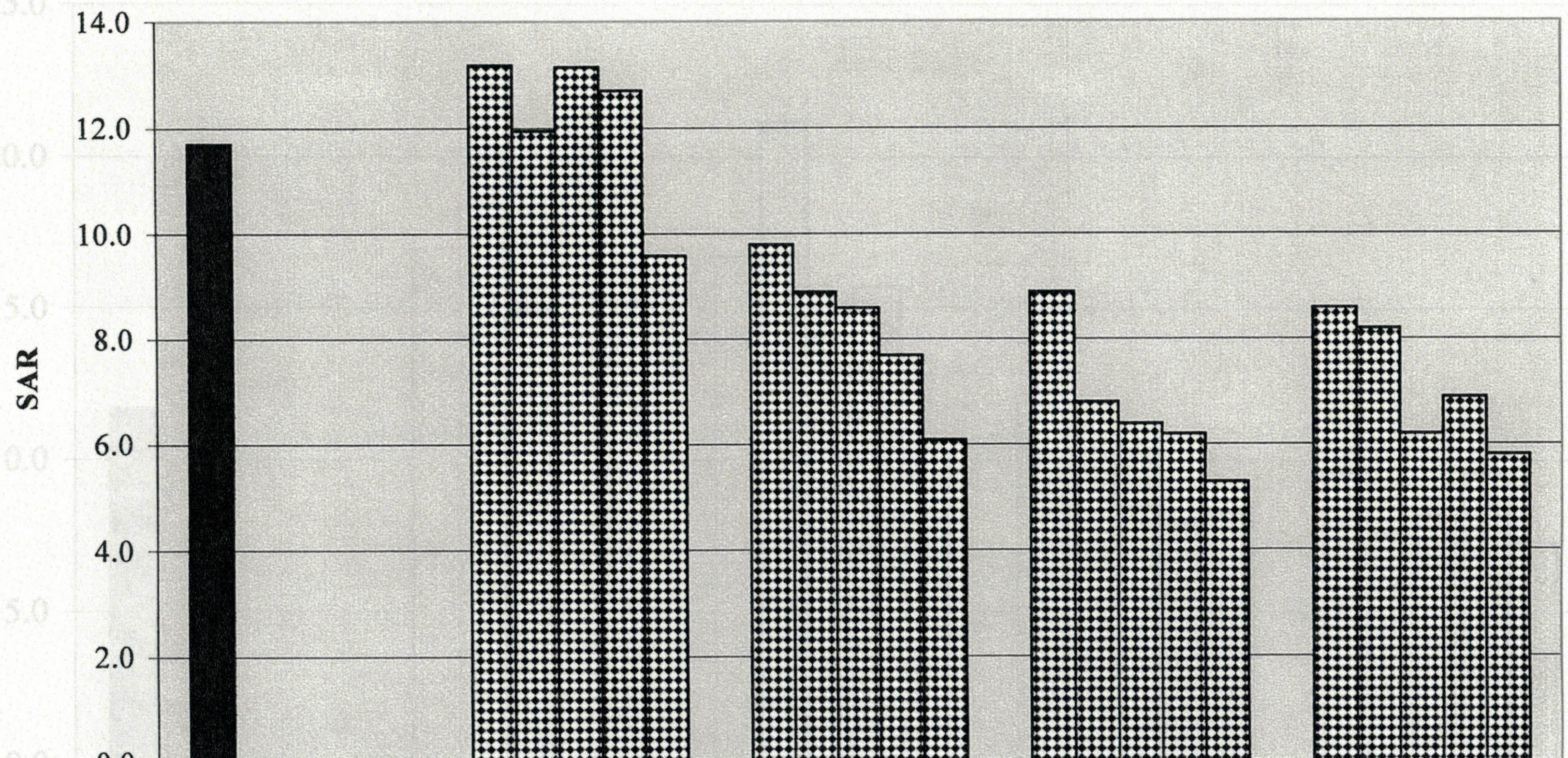
	Nat	11.2 Mg/ha	22.4 Mg/ha	224 Mg/ha	11.2 Mg/ha + Acid
Leach 1	11.7	21.6	18.2	12.9	11.1
Leach 2		9.2	6.3	11.2	11.1
Leach 3		18.2	5.4	10.9	10.6
Leach 4		19.6	5.1	5.0	10.1
Leach 5		16.6	3.4	5.3	9.6

Figure 34. Site 1- Bosville(Choctaw Co.)- Effects of Leaching and Hydrated Lime Application on Sample No. 7 (ODOT No. 15)
Nat= Natural (no amendment applied)



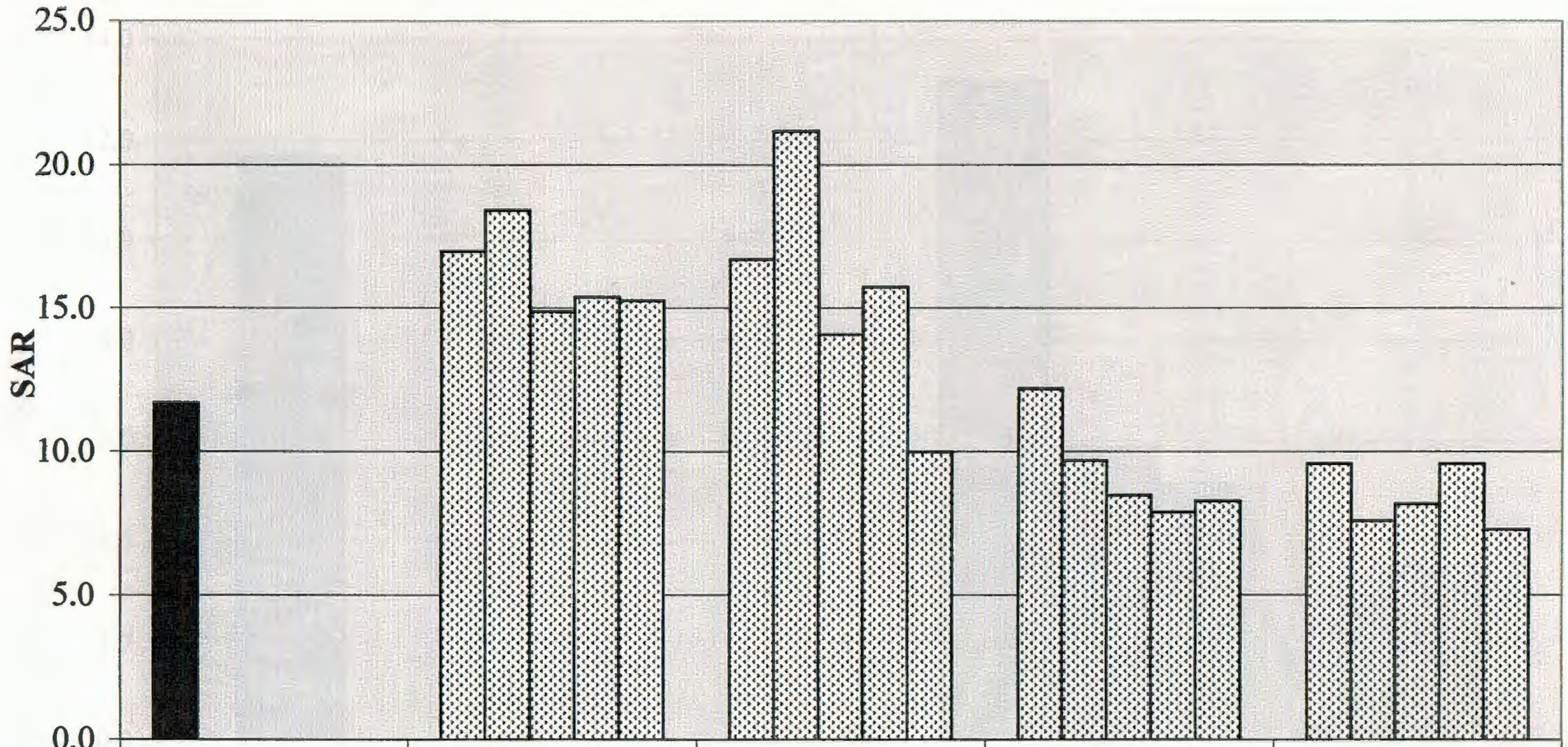
	Nat	11.2 Mg/ha	22.4 Mg/ha	224 Mg/ha	11.2 Mg/ha + Acid	22.4 Mg/ha + Acid
Leach 1	11.7	12.0	15.7	19.3	6.3	8.8
Leach 2		11.4	18.2	9.6	5.9	7.9
Leach 3		9.4	14.1	14.5	5.8	7.6
Leach 4		13.3	14.7	13.6	5.3	7.5
Leach 5		13.1	6.6	12.1	5.4	6.7

Figure 35. Site 1- Bosville(Choctaw Co.)- Effects of Leaching and Fly Ash Application on Sample No. 7 (ODOT No. 15)
Nat= Natural (no amendment applied)



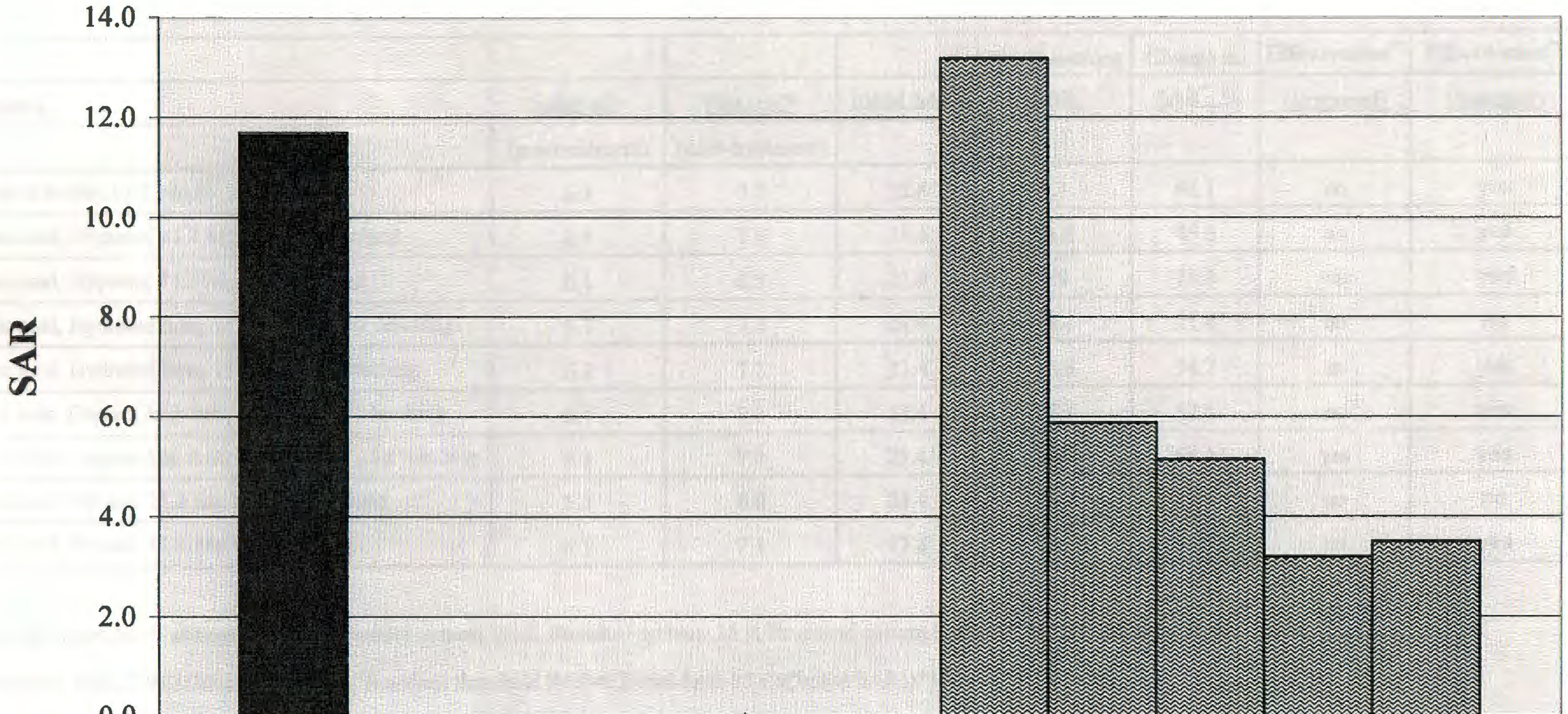
	Nat	11.2 Mg/ha	224 Mg/ha	11.2 Mg/ha + Acid	22.4 Mg/ha + Acid
Leach 1	11.7	13.2	9.8	8.9	8.6
Leach 2		12.0	8.9	6.8	8.2
Leach 3		13.2	8.6	6.4	6.2
Leach 4		12.7	7.7	6.2	6.9
Leach 5		9.6	6.1	5.3	5.8

Figure 36. Site 1- Bosville(Choctaw Co.)- Effects of Leaching and Cement Kiln Dust Application on Sample No. 7 (ODOT No. 15)
Nat= Natural (no amendment applied)



	Nat	11.2 Mg/ha	22.4 Mg/ha	11.2 Mg/ha + Acid	22.4 Mg/ha + Acid
Leach 1	11.7	17.0	16.7	12.2	9.6
Leach 2		18.4	21.2	9.7	7.6
Leach 3		14.9	14.1	8.5	8.2
Leach 4		15.4	15.7	7.9	9.6
Leach 5		15.3	10.0	8.3	7.3

Figure 37. Site 1- Bosville (Choctaw Co.)- Effects of Leaching and Humate Application on Sample No. 7 (ODOT No. 15)
Nat= Natural (no amendment applied)



	Nat	11.2 Mg/ha
Leach 1	11.7	13.2
Leach 2		5.9
Leach 3		5.1
Leach 4		3.2
Leach 5		3.5

Figure 38. Site 1- Bosville (Choctaw Co.)- Effects of Leaching and Calcium Chloride Application on Sample No. 7 (ODOT No. 15)
Nat= Natural (no amendment applied)

Table 13. Site 3. Amendment Study- Wing (LeFlore) Bt1 Horizon (Sample No. 15, ODOT No. 4) Treatment Data.

Treatments[#]	Initial pH* (pre-treatment)	Final pH* (post-treatment)	Initial SAR[+]	Final Leaching SAR[+]	Change in SAR[+], %	Effectiveness[++] (Proposed)	Effectiveness[++] (Standard)
Calcium chloride, 11.2 Mg ha^{-1}, leaching	6.1	7.1	23.4	9.1	61.1	no	yes
Sulfuric acid, Gypsum, 11.2 Mg ha^{-1},1st leaching	6.1	7.4	23.4	11.8	49.6	no	yes
Sulfuric acid, Gypsum, 11.2 Mg ha^{-1}, leaching	6.1	6.5	23.4	5.9	74.8	yes	yes
Sulfuric acid, Hydrated lime, 11.2 Mg ha^{-1},1st leaching	6.1	7.7	23.4	18.4	21.4	no	no
Sulfuric acid, Hydrated lime, 11.2 Mg ha^{-1}, leaching	6.1	7.2	23.4	10.6	54.7	no	yes
Sulfuric acid, Cement kiln dust, 11.2 Mg ha^{-1}, leaching	6.1	8.0	23.4	11.1	52.6	no	yes
Sulfuric acid, Cement kiln dust, 11.2 Mg ha^{-1}, 1st leaching	6.1	7.4	23.4	7.4	68.4	yes	yes
Sulfuric acid, Fly ash, 11.2 Mg ha^{-1},1st leaching	6.1	8.0	23.4	15.7	32.9	no	no
Sulfuric acid, Fly ash, 11.2 Mg ha^{-1}, leaching	6.1	7.1	23.4	11.3	51.7	no	yes

[&]Threshold values for % change in SAR: Proposed system- 66.2, Standard system- 35.9; Proposed system threshold SAR=((Initial SAR-the proposed SAR (7.9))/ (Initial SAR)*100; Standard threshold SAR=((Initial SAR-15.0)/(Initial SAR))*100

[#]Leaching included 5 successive saturations/extractions of treated soil

*Pre-treatment pH=pH reading before chemical treatment; *Post-treatment pH=pH reading after chemical treatment;

[+]Initial SAR - Sodium Adsorption Ratio without chemical treatment ;[+] Final SAR - Sodium Adsorption Ratio with chemical treatment; [+] Change in SAR=((Initial SAR - Final SAR)/Initial SAR)*100

[++] Evaluation based on decrease in SAR in relation to diagnostic value for sodic classification

CKD, FL, and HU. Table 13 summarizes results of amending the Wing soil. Combinations of G or CKD and SA successfully reduced the SAR of the soil.

Results of Amending the Bn1 horizon of the Pawhuska (McClain Co.) soil (Site 5, Part II, page 62)

The Pawhuska (McClain Co.) sampling location is in the central part of Oklahoma. The Bn1 horizon is sodic-moderately saline (EC equal to 1.0, SAR equal to 12.2) Amendments tested on the Pawhuska soil include G, HL, FL, CKD, HU, CA, SA. Table 14 summarizes the results of amending the Pawhuska soil. The most successful amendments for treatment of the soil include G, HL, and CA.

Results of Amending the Btn2 and Bt3 horizons of the Dwight (Osage Co.) soil (Site 11, Part II, page 126)

The Dwight (Osage Co.) sampling location is in the northcentral part of Oklahoma. The Btn2 and Bt3 horizons are sodic-moderately saline (EC equal to 3.8 and 3.9, SAR equal to 28.4 and 32.5, respectively). Amendments tested on the Dwight soils include G, HL, FL, CKD, HU, CA, and SA. None of the treatments reduced SAR values of the soils below 7.9. Table 15 summarizes the results of all the amendments for the Dwight (Osage Co.) soils.

Results of Amending the Btkn3 and Btnq4 horizons of the Doolin (Payne Co.) soil (Site 14, Part II, page 160

The Doolin (Payne Co.) sampling location is in the central part of Oklahoma. The Btkn3 and Btnq4 horizons are sodic-moderately saline (EC equal to 7.2 and 4.0, SAR equal to 14.8 and 21.3, respectively). Treatments included G, HL, FL, CKD, HU, CA and SA (Table 16).

Table 14. Site 5. Amendment Study- Pawhuska (McClain) Bn1 Horizon (Sample No. 28, ODOT No. 16) Treatment Data

Treatments[#]	Initial pH[*] (pre-treatment)	Final pH[*] (post-treatment)	Initial SAR[+]	Final Leaching SAR[+]	Change in SAR[+], %	Effectiveness[++] (Proposed)	Effectiveness[++] (Standard)
Gypsum, site specific, 4.86 $Mg\ ha^{-1}$	8.4	7.8	12.2	10.6	13.1	no	yes
Gypsum, 11.2 $Mg\ ha^{-1}$, leaching	8.4	7.9	12.2	10.5	13.9	no	yes
Gypsum, 11.2 $Mg\ ha^{-1}$, leaching	8.4	7.5	12.2	7.2	41.0	yes	yes
Gypsum, 22.4 $Mg\ ha^{-1}$, 1st leaching	8.4	7.7	12.2	9.8	19.7	no	yes
Gypsum, 22.4 $Mg\ ha^{-1}$, leaching	8.4	7.2	12.2	6.2	49.2	yes	yes
Gypsum, 224 $Mg\ ha^{-1}$	8.4	8.1	12.2	6.8	44.3	yes	yes
Hydrated lime, site specific, 3.52 $Mg\ ha^{-1}$	8.4	8.4	12.2	8.7	28.7	no	yes
Hydrated lime, 11.2 $Mg\ ha^{-1}$, 1st leaching	8.4	7.9	12.2	25.3	-107.4	no	no
Hydrated lime, 11.2 $Mg\ ha^{-1}$, leaching	8.4	7.2	12.2	6.1	50.0	yes	yes
Hydrated lime, 22.4 $Mg\ ha^{-1}$, 1st leaching	8.4	11.3	12.2	15.2	-24.6	no	no
Hydrated lime, 22.4 $Mg\ ha^{-1}$, leaching	8.4	9.2	12.2	6.0	50.8	yes	yes
Hydrated lime, 224 $Mg\ ha^{-1}$	8.4	12.7	12.2	10.5	13.9	no	yes
Fly ash, site specific, 11.0 $Mg\ ha^{-1}$	8.4	7.2	12.2	9.3	23.8	no	yes
Fly ash, 11.2 $Mg\ ha^{-1}$, 1st leaching	8.4	8.2	12.2	23.0	-88.5	no	no
Fly ash, 11.2 $Mg\ ha^{-1}$, leaching	8.4	7.6	12.2	13.3	-9.0	no	yes
Fly ash, 22.4 $Mg\ ha^{-1}$, 1st leaching	8.4	7.7	12.2	14.6	-19.7	no	yes
Fly ash, 224 $Mg\ ha^{-1}$	8.4	10.9	12.2	20.2	-65.6	no	no
Cement kiln dust, site specific, 4.07 $Mg\ ha^{-1}$	8.4	7.5	12.2	7.0	42.6	yes	yes
Cement kiln dust, 11.2 $Mg\ ha^{-1}$, 1st leaching	8.4	8.8	12.2	12.1	0.8	no	yes
Cement kiln dust, 11.2 $Mg\ ha^{-1}$, leaching	8.4	8.3	12.2	10.3	15.6	no	yes
Cement kiln dust, 224 $Mg\ ha^{-1}$	8.4	11.7	12.2	16.2	-32.8	no	no
Humate, 11.2 $Mg\ ha^{-1}$, 1st leaching	8.4	7.9	12.2	8.4	31.1	no	yes
Humate, 11.2 $Mg\ ha^{-1}$, leaching	8.4	7.9	12.2	10.1	17.2	no	yes
Humate, 22.4 $Mg\ ha^{-1}$, 1st leaching	8.4	7.8	12.2	15.8	-29.5	no	no
Humate, 22.4 $Mg\ ha^{-1}$, leaching	8.4	8.2	12.2	9.9	18.9	no	yes

Table 14. Site 5. Amendment Study- Pawhuska (McClain) Bn1 Horizon (Sample No. 28, ODOT No. 16)
Treatment Data (cont.)

Treatments#	Initial pH*	Final pH*	Initial SAR+	Final Leaching SAR+	Change in SAR+, %	Effectiveness++ (Proposed)	Effectiveness++ (Standard)
	(pre-treatment)	(post-treatment)					
Calcium chloride, 11.2 $Mg\ ha^{-1}$, 1st leaching	8.4	7.8	12.2	11.9	2.5	no	yes
Calcium chloride, 11.2 $Mg\ ha^{-1}$, leaching	8.4	7.2	12.2	6.4	47.5	yes	yes
Sulfuric Acid, 36 meq/100 g soil, 1st leaching	8.4	7.7	12.2	29.5	-141.8	no	no
Sulfuric Acid, 36 meq/100 g soil	8.4	7.4	12.2	14.2	-16.4	no	yes

^Threshold values for % change in SAR: Proposed system- 35.2, Standard system- -23.0; Proposed system threshold SAR= ((Initial SAR-the proposed SAR (7.9)/(Initial SAR))*100; Standard threshold SAR=((Initial SAR-15.0)/(Initial SAR))*100

#Leaching included 5 successive saturations/extractions of treated soil

*Pre-treatment pH=pH reading before chemical treatment; *Post-treatment pH=pH reading after chemical treatment;

+Initial SAR - Sodium Adsorption Ratio without chemical treatment ;+ Final SAR - Sodium Adsorption Ratio with chemical treatment; + Change in SAR=((Initial SAR - Final SAR)/Initial SAR)*100.

++ Evaluation based on decrease in SAR in relation to diagnostic value for sodic classification;

##All other treatments including sulfuric acid were at a rate of 7 meq/100 g soil sulfuric acid.

Table 15. Site 11. Amendment Study- Dwight (Osage) Btn2 and Bt3 Horizons (Sample Nos. 64 and 65, ODOT Nos. 43 and 44, respectively) Treatment Data.

Treatments[#]	Sample No.[*] (pre-treatment)	Initial pH[*] (pre-treatment)	Final pH[*] (post-treatment)	Initial SAR[+]	Final Leaching SAR[+]	Change in SAR[+], %	Effectiveness[++] (Proposed)	Effectiveness[++] (Standard)
Gypsum, site specific 2.24 Mg ha^{-1}	64	8.4	8.9	28.4	26.4	7.0	no	no
Gypsum, 11.2 Mg ha^{-1}, 1st leaching	64	8.4	7.9	28.4	24.8	12.7	no	no
Gypsum, 11.2 Mg ha^{-1}, leaching	64	8.4	7.5	28.4	16.5	41.9	no	no
Gypsum, 22.4 Mg ha^{-1}, 1st leaching	64	8.4	7.7	28.4	28.1	1.1	no	no
Gypsum, 22.4 Mg ha^{-1}, leaching	64	8.4	7.3	28.4	12.4	56.3	no	yes
Gypsum, 224 Mg ha^{-1}	64	8.4	8.4	28.4	23.9	15.8	no	no
Hydrated lime, site specific 1.61Mg ha^{-1}	65	8.4	7.9	32.5	24.2	25.5	no	no
Hydrated lime, 11.2 Mg ha^{-1}, 1st leaching	65	8.4	9.9	32.5	32.1	1.2	no	no
Hydrated lime, 11.2 Mg ha^{-1}, leaching	65	8.4	7.5	32.5	12.7	60.9	no	yes
Hydrated lime, 22.4 Mg ha^{-1}, 1st leaching	65	8.4	10.8	32.5	35.9	-10.5	no	no
Hydrated lime, 22.4 Mg ha^{-1}, leaching	65	8.4	8.4	32.5	23.0	29.2	no	no
Hydrated lime, 224 Mg ha^{-1}	64	8.4	12.9	28.4	24.0	15.5	no	no
Fly ash, site specific 5.06 Mg ha^{-1}	65	8.4	7.5	32.5	20.0	38.5	no	no
Fly ash, 11.2 Mg ha^{-1}, 1st leaching	65	8.4	8.1	32.5	27.4	15.7	no	no
Fly ash, 11.2 Mg ha^{-1}, leaching	65	8.4	8.3	32.5	24.4	24.9	no	no
Fly ash, 22.4 Mg ha^{-1}, 1st leaching	65	8.4	7.9	32.5	22.9	29.5	no	no
Fly ash, 22.4 Mg ha^{-1}, leaching	65	8.4	7.3	32.5	15.6	52.0	no	no
Fly ash, 224 Mg ha^{-1}	64	8.4	10.7	28.4	26.0	8.5	no	no
Cement kiln dust, site specific 1.86 Mg ha^{-1}	64	8.4	7.6	32.5	28.4	12.6	no	no
Cement kiln dust, 11.2 Mg ha^{-1}, leaching	64	8.4	7.6	32.5	28.4	12.6	no	no
Cement kiln dust, 11.2 Mg ha^{-1}, leaching	64	8.4	7.6	32.5	28.4	12.6	no	no
Cement kiln dust, 224 Mg ha^{-1}	64	8.4	12.1	32.5	28.4	12.6	no	no
Humate, 11.2 Mg ha^{-1},1st leaching	65	8.4	8.3	32.5	33.2	-2.2	no	no
Humate, 11.2 Mg ha^{-1}, leaching	65	8.4	8.0	32.5	20.7	36.3	no	no
Humate, 22.4 Mg ha^{-1}, 1st leaching	65	8.4	7.8	32.5	19.8	39.1	no	no
Humate, 22.4 Mg ha^{-1}, leaching	65	8.4	7.5	32.5	15.5	52.3	no	no

Table 15. Site 11. Amendment Study- Dwight (Osage) Btn2 and Bt3 Horizons (Sample Nos. 64 and 65, ODOT Nos. 43 and 44, respectively) Treatment Data (Cont.)

Treatments[#]	Sample No.*	Initial pH* (pre-treatment)	Final pH* (post-treatment)	Initial SAR[+]	Final Leaching SAR[+]	Change in SAR[+], %	Effectiveness[++] (Proposed)	Effectiveness[++] (Standard)
Calcium chloride, 11.2 Mg ha^{-1}, 1st leaching	65	8.4	7.8	32.5	28.6	12.0	no	no
Calcium chloride, 11.2 Mg ha^{-1}, leaching	65	8.4	7.6	32.5	18.9	41.8	no	no
Sulfuric acid (36 meq/100 g soil)[##], 1st leaching	65	8.4	8.8	32.5	71.4	-119.7	no	no
Sulfuric acid (36 meq/100 g soil)[##], leaching	65	8.4	8.3	32.5	66.3	-104.0	no	no

[&]Threshold values for % change in SAR: Proposed system- 60.9, Standard system- 47.2; Proposed system threshold SAR=((Initial SAR-the proposed SAR (7.9))/ (Initial SAR)*100; Standard threshold SAR=((Initial SAR-15.0)/(Initial SAR))*100

[#]Leaching included 5 successive saturations/extractions of treated soil

*Pre-treatment pH=pH reading before chemical treatment; *Post-treatment pH=pH reading after chemical treatment;

[+]Initial SAR - Sodium Adsorption Ratio without chemical treatment ;[+] Final SAR - Sodium Adsorption Ratio with chemical treatment; [+] Change in SAR=((Initial SAR - Final SAR)/Initial SAR)*100.

[++] Evaluation based on decrease in SAR in relation to diagnostic value for sodic classification;

[##]All other treatments including sulfuric acid were at a rate of 7 meq/100 g soil sulfuric acid.

Table 16. Site 14. Amendment Study- Doolin (Payne) Btkn3 and Btnyq4 Horizons (Sample Nos. 85 and 86, ODOT Nos. 55 and 56, respectively) Treatment Data

Treatments[#]	Sample No.*	Initial pH* (pre-treatment)	Final pH* (post-treatment)	Initial SAR[+]	Final Leaching SAR[+]	Change in SAR[+], %	Effectiveness[++] (Proposed)	Effectiveness[++] (Standard)
Gypsum, site specific 7.39 Mg ha^{-1},	85	7.6	7.9	21.3	14.4	32.4	no	yes
Gypsum, 11.2 Mg ha^{-1}, 1st leaching	85	7.6	7.7	21.3	14.8	30.5	no	yes
Gypsum, 11.2 Mg ha^{-1}, leaching	85	7.6	7.2	21.3	7.4	65.3	yes	yes
Gypsum, 22.4 Mg ha^{-1}, 1st leaching	85	7.6	7.8	21.3	13.9	34.7	no	yes
Gypsum, 22.4 Mg ha^{-1}, leaching	85	7.6	7.3	21.3	8.0	62.4	yes	yes
Gypsum, 224 Mg ha^{-1}	85	7.6	7.9	21.3	12.6	40.8	no	yes
Hydrated lime, site specific 5.37 Mg ha^{-1}	86	7.6	7.5	21.3	15.7	26.3	no	no
Hydrated lime, 11.2 Mg ha^{-1}, 1st leaching	86	7.6	10.0	21.3	51.6	-142.3	no	no
Hydrated lime, 11.2 Mg ha^{-1}, leaching	86	7.6	7.2	21.3	11.7	45.1	no	yes
Hydrated lime, 22.4 Mg ha^{-1}, 1st leaching	86	7.6	11.1	21.3	53.2	-149.8	no	no
Hydrated lime, 22.4 Mg ha^{-1}, leaching	86	7.6	8.6	21.3	11.5	46.0	no	yes
Hydrated lime, 224 Mg ha^{-1}	85	7.6	12.8	21.3	17.8	16.4	no	no
Fly ash, 11.2 Mg ha^{-1}, 1st leaching	86	7.6	7.7	21.3	33.3	-56.3	no	no
Fly ash, 11.2 Mg ha^{-1}, leaching	86	7.6	7.4	21.3	10	53.1	yes	yes
Fly ash, site specific, 16. 8 Mg ha^{-1}	86	7.6	7.8	21.3	14.4	32.4	no	yes
Fly ash, 22.4 Mg ha^{-1}, 1st leaching	86	7.6	7.5	21.3	11.8	44.6	no	yes
Fly ash, 22.4 Mg ha^{-1}, leaching	86	7.6	7.4	21.3	10.5	50.7	yes	yes
Fly ash, 224 Mg ha^{-1}	85	7.6	10.8	21.3	14.0	34.3	no	yes
Cement kiln dust, site specific, 6.2 Mg ha^{-1}	85	7.6	7.1	21.3	11.8	44.6	no	yes
Cement kiln dust, 11.2 Mg ha^{-1}, 1st leaching	85	7.6	7.7	21.3	13.9	34.7	no	yes
Cement kiln dust, 11.2 Mg ha^{-1}, leaching	85	7.6	7.1	21.3	9.2	56.8	no	yes
Cement kiln dust, 224 Mg ha^{-1}	85	7.6	12.7	21.3	22.9	-7.5	no	no
Humate, 11.2 Mg ha^{-1}, 1st leaching	86	7.6	7.8	21.3	20.7	2.8	no	no
Humate, 11.2 Mg ha^{-1}, leaching	86	7.6	7.5	21.3	16.7	21.6	no	no
Humate, 22.4 Mg ha^{-1}, 1st leaching	86	7.6	8	21.3	13.7	35.7	no	yes
Humate, 22.4 Mg ha^{-1}, leaching	86	7.6	7.6	21.3	10.9	48.8	no	yes

Table 16. Site 14. Amendment Study- Doolin (Payne) Btkn3 and Btnyq4 Horizons (Sample Nos. 85 and 86, ODOT Nos. 55 and 56, respectively) Treatment Data (cont.)

Treatments[#]	Sample No.*	Initial pH*	Final pH*	Initial SAR[+]	Final Leaching SAR[+]	Change in SAR[+], %	Effectiveness[++] (Proposed)	Effectiveness[++] (Standard)
		(pre-treatment)	(post-treatment)					
Calcium chloride, 11.2 Mg ha^{-1}, 1st leaching	86	7.6	7.2	21.3	14.7	31.0	no	yes
Calcium chloride, 11.2 Mg ha^{-1}, leaching	86	7.6	7.0	21.3	9.8	54.0	no	yes
Sulfuric acid (36 meq/100 g soil)[##], leaching	86	7.6	7.4	21.3	33.9	-59.2	no	no
Sulfuric acid (36 meq/100 g soil)[##], leaching	86	7.6	7.5	21.3	21.1	0.9	no	no

[&]Threshold values for % change in SAR: Proposed system- 62.9, Standard system- 29.6; Proposed system threshold SAR=((Initial SAR-the proposed SAR (7.9))/ (Initial SAR)*100;
Standard threshold SAR=((Initial SAR-15.0)/(Initial SAR))*100

[#]Leaching included 5 successive saturations/extractions of treated soil

*Pre-treatment pH=pH reading before chemical treatment; *Post-treatment pH=pH reading after chemical treatment;

[+]Initial SAR - Sodium Adsorption Ratio without chemical treatment ;[+] Final SAR - Sodium Adsorption Ratio with chemical treatment; [+] Change in SAR=((Initial SAR - Final SAR)/Initial SAR)*100.

[++] Evaluation based on decrease in SAR in relation to diagnostic value for sodic classification;

[##]All other treatments including sulfuric acid were at a rate of 7 meq/100 g soil sulfuric acid.

Effective treatments for the soil include G and FA applications.

Results of Amending the BCk horizon of the Hinkle (Kiowa Co.) soil (Site 22, Part II, page 232)

The Hinkle (Kiowa Co.) sampling location is in the southwestern part of Oklahoma. The BCk horizon is sodic-moderately saline (EC equal to 6.8, SAR equal to 29.9). Treatments included G, HL, FL, CKD, HU, CA, and SA.

Evaluation of Treatments

Selection of appropriate treatments for reclamation depends on the effectiveness of the amendments in improving soil properties and plant growth. The ability of amendments to favorably influence the EC, pH, SAR and amount of dispersion in a soil is important in the evaluation and selection of an amendment. Differences in effective time for amendments to work between laboratory studies and actual field applications are important factors which need to be tested.

Results of this study indicate the properties of the soil are important to consideration of the proper treatment. None of the treatments reduced the SAR value of the Dwight (Osage Co.) horizons below the desired value and nearly all of the treatments successfully lowered SAR values for the Wing, Bosville, and Pawhuska soils. Increasing salinity and sodicity hindered the ability of amendments to effectively reclaim sodic soils as evidenced by the number of treatments not working on the Dwight, Doolin, and Hinkle soils. If standard diagnostic values for sodic soils (USSL, 1954) are the criterion, then effective reclamations of sodic soils in

Table 17. Site 22. Amendment Study- Hinkle (Kiowa) BCk Horizon (Sample No. 146, ODOT No. 97) Treatment Data

Treatments#	Initial pH* (pre-treatment)	Final pH* (post-treatment)	Initial SAR+	Final Leaching SAR+	Change in SAR+, %	Effectiveness++ (Proposed)	Effectiveness++ (Standard)
Gypsum, site specific 7.73 Mg/ha	7.8	7.9	29.9	21.1	29.4	no	no
Gypsum, 11.2 Mg ha-1, 1st leaching	7.8	7.8	29.9	25.1	16.1	no	no
Gypsum, 11.2 Mg ha^{-1}, leaching	7.8	7.2	29.9	7.4	75.3	yes	yes
Gypsum, 22.4 Mg ha^{-1}, 1st leaching	7.8	7.7	29.9	24.5	18.1	no	no
Gypsum, 22.4 Mg ha^{-1}, leaching	7.8	7.4	29.9	8.4	71.9	no	yes
Gypsum, 224 Mg ha^{-1}	7.8	7.8	29.9	17.9	40.1	no	no
Hydrated lime, site specific 5.60 Mg/ha	7.8	7.8	29.9	27.7	7.4	no	no
Hydrated lime, 11.2 Mg ha^{-1}, 1st leaching	7.8	10.7	29.9	60.3	-101.7	no	no
Hydrated lime, 11.2 Mg ha^{-1}, leaching	7.8	7.6	29.9	9.2	69.2	no	yes
Hydrated lime, 22.4 Mg ha^{-1}, 1st leaching	7.8	10.7	29.9	80.4	-168.9	no	no
Hydrated lime, 22.4 Mg ha^{-1}, leaching	7.8	9.8	29.9	11.5	61.5	no	yes
Hydrated lime, 224 Mg ha^{-1}	7.8	12.8	29.9	37.7	-26.1	no	no
Fly ash, 11.2 Mg ha^{-1},1st leaching	7.8	8.0	29.9	29.6	1.0	no	no
Fly ash, 11.2 Mg ha^{-1}, leaching	7.8	8.0	29.9	25.4	15.1	no	no
Fly ash, site specific 17.54 Mg/ha	7.8	7.9	29.9	21.8	27.1	no	no
Fly ash, 22.4 Mg ha^{-1}, 1st leaching	7.8	7.4	29.9	22.6	24.4	no	no
Fly ash, 22.4 Mg ha^{-1}, leaching	7.8	7.7	29.9	20.1	32.8	no	no
Fly ash, 224 Mg ha^{-1}	7.8	11.5	29.9	34.0	-13.7	no	no
Cement kiln dust, site specific 6.47 Mg/ha	7.8	7.1	29.9	15.5	48.2	no	no
Cement kiln dust, 11.2 Mg ha^{-1}, 1st leaching	7.8	7.9	29.9	18.7	37.5	no	no
Cement kiln dust, 11.2 Mg ha^{-1}, leaching	7.8	7.1	29.9	12.9	56.9	no	yes
Cement kiln dust, 224 Mg ha^{-1}	7.8	12.5	29.9	33.1	-10.7	no	no
Humate, 11.2 Mg ha^{-1}, 1st leaching	7.8	8.1	29.9	30.1	-0.7	no	no
Humate, 11.2 Mg ha^{-1}, leaching	7.8	8.0	29.9	27.2	9.0	no	no
Humate, 22.4 Mg ha^{-1}, 1st leaching	7.8	8.2	29.9	34.9	-16.7	no	no
Humate, 22.4 Mg ha^{-1}, leaching	7.8	7.6	29.9	12.1	59.5	no	yes

Table 17. Site 22. Amendment Study- Hinkle (Kiowa) BCk Horizon (Sample No. 146, ODOT No. 97) Treatment Data (cont.)

Treatments[#]	Initial pH* (pre-treatment)	Final pH* (post-treatment)	Initial SAR[+]	Final Leaching SAR[+]	Change in SAR[+], %	Effectiveness[++] (Proposed)	Effectiveness[++] (Standard)
Calcium chloride, 11.2 Mg ha^{-1}, 1st leaching	7.8	7.4	29.9	20.7	30.8	no	no
Calcium chloride, 11.2 Mg ha^{-1}, leaching	7.8	7.2	29.9	14.7	50.8	no	yes
Sulfuric acid (36 meq/100 g soil)[##], 1st leaching	7.8	8.6	29.9	68.0	-127.4	no	no
Sulfuric acid (36 meq/100 g soil)[##], leaching	7.8	7.5	29.9	51.4	-71.9	no	no

[a]Threshold values for % change in SAR: Proposed system- 73.6, Standard system- 49.8; Proposed system threshold SAR=((Initial SAR-the proposed SAR (7.9))/ (Initial SAR)*100; Standard threshold SAR=((Initial SAR-15.0)/(Initial SAR))*100

[#]Leaching included 5 successive saturations/extractions of treated soil

*Pre-treatment pH=pH reading before chemical treatment; *Post-treatment pH=pH reading after chemical treatment;

[+]Initial SAR - Sodium Adsorption Ratio without chemical treatment ;[+] Final SAR - Sodium Adsorption Ratio with chemical treatment; [+] Change in SAR=((Initial SAR - Final SAR)/Initial SAR)*100.

[++] Evaluation based on decrease in SAR in relation to diagnostic value for sodic classification;

[##]All other treatments including sulfuric acid were at a rate of 7 meq/100 g soil sulfuric acid.

Oklahoma are overestimated. Reclamation of sodic soils in Oklahoma will improve if diagnostic criterion proposed in this report become the standard.

SUMMARY

Twenty-three soils were sampled and characterized from locations within sodic soil mapping units across Oklahoma. Twenty-two soils represent the range in sodic soils for Oklahoma. One soil sampled as the Huska series (sodic) did not contain any sodic, saline, or dispersive properties and is considered a "normal" soil (classified as the Zanies series). All other soils did contain sodic, saline, and dispersive properties as predicted from county soil survey maps (NRCS, USDA).

The twenty-three soils sampled were classified following the current U.S. soil classification system (Soil Survey Staff, 1999). Several sodic-dispersive soils did not classify as natric (sodic-dispersive) according to (Soil Survey Staff, 1999). Sodic properties for these "non-natric" soils were either deeper than or contained lower SAR values compared to current natric soil classification. This report recommends a revision or expansion the natric definition (Soil Survey Staff, 1999) to include these "non-natric" soils as natric. The current classification system may be biased toward agronomic interpretation of the subsoil for shallow root growth compared to the same subsoil used as engineering soil materials.

An improved correlation of sodic soil series names with exact field characteristics is needed to better classify these soils (Soil Survey Staff, 1999). The NRCS, USDA has done a good job identifying sodic soil across Oklahoma. However, sampled soils classified according to soil taxonomy (Soil Survey Staff, 1999) often did not match currently used sodic soil series names used in Oklahoma. This report can serve as an initial step for improved sodic soil correlation and classification.

County soil survey maps (NRCS, USDA) can be used to locate sodic soils to within 200 m of a specific location. However, if site specific information is needed on exact location of

sodic soils to less than 200 m a detailed field investigation is required. These county soil survey maps are digitized and can quickly and easily be used to identify sodic soils as they intersect roadways or other features. Several counties in southeastern Oklahoma contain sodic soils that are not identified by county soil surveys (i.e. Choctaw County). This report recommends a field evaluation of soils in southeastern Oklahoma counties to identify the distribution of sodic soils. Also, a model to predict the spatial distribution of sodic soils in small areas (less than 200 m x 200 m) is needed. Currently, no information is available to predict field variability of sodic soil mapping units (including both laterally and with depth).

The origin of natural sodic soil conditions in Oklahoma is from a ground water source. Sodium salts occurring in Cretaceous, Permian, and Pennsylvanian rocks are dissolved by ground water. The ground water moves laterally and affects stream deposits (alluvium) and soils adjacent to salty rocks. Sodic soils form from sediments containing elevated amounts of salt. Sodic soils in eastern Oklahoma contain sodic properties at a greater depth compared to sodic soils in western Oklahoma because of lower evapotranspiration and higher precipitation in eastern Oklahoma compared to western Oklahoma.

Sodic soils are not easily identified during field inspection using standard procedures. Surface features are sometimes used including the identification of slickspots. However, not all sodic soil areas contain or are identified by slickspots. Saline-sodic soils are identified by a white surface salt crust (efflorescence) formed during dry periods but this efflorescence does not identify non-saline, sodic-dispersive soils. Excavating the soil and reviewing the soil profile can reveal sodic soil features including siltans and columnar structure. The presence of columnar structure was not a consistent indicator of sodic soil. Siltans were present in over 80% of the soils in the study and can identify most sodic soils using a shallow excavation. Siltans and columnar structure identify the upper part of the sodic subsoil but do not adequately identify the total thickness and depth of sodic conditions. Naturally occurring sodic soil always contains a high clay content in the subsoil compared to surface horizons. However this clay distribution is not unique to sodic soils. Often field identification of sodic soils is enhanced by the accelerated erosion associated with dispersion that is observed along natural and human induced exposures such as gullies, road sides, and local borrow pits.

The double hydrometer test was used to determine dispersion percentage for sodic soils in this study. The double hydrometer test was selected as a standard because it is a quantitative test that is cited as reliable in predicting actual field problems. The pinhole and crumb tests were also included in the study to predict dispersion and were compared to the double hydrometer test. The double hydrometer, pinhole, and crumb tests were compared to laboratory determined soil properties which are often used by soil scientist and civil engineers to predict dispersion including SAR, ESP, EC, saturated paste extractable cations and anions, pH, clay mineralogy, and gypsum content (estimated from field soil morphology). The amount of sodium in the soil solution as measured by SAR and ESP is needed to predict dispersive conditions in sodic soils. However, SAR and ESP alone do not explain dispersive potential. If soil EC is included along with SAR or ESP then dispersion is adequately predicted. Problems using SAR and EC to predict soil dispersion can occur because of the presence of soil-formed gypsum, variable magnesium content, unique mineralogy, extreme pH and EC values, and variable sulfate, chloride, and bicarbonate content. The crumb test did not consistently predict dispersion and therefore should not be used as a rapid field test. The crumb test failed to predict dispersion for soils with a large dissolved salt concentration (high EC). The pinhole test did predict dispersion. Pinhole test values of slightly to moderately dispersive or greater were identified as predicting dispersion. However, the levels of dispersion above slight dispersive (ND3) as used in the pinhole test did not correlate to the actual percentage as determined by the double hydrometer test.

Gypsum and leaching with water are effective amendments to lower SAR in sodic-dispersive soils. The remediation of sodic soil is dependent on the amount of salts and sodium in the soil. Amendments tested in this study proved more effective on soils with lower EC (less than 1.0-2.5 ds/m) and SAR (less than 12.0) values than on soils with higher EC (greater than 3.5-7.0 ds/m) and SAR (greater than 30) values. Increasing the amount of salts and sodium hindered the ability of amendments to reduce soil SAR values below sodic levels (successive addition and removal of water). Leaching after application of amendments resulted in lowering of SAR values. Comparison of laboratory results with field results are necessary for proper evaluation of amending materials and treatments.

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